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OVERLAND FLOW TREATMENT OF DOMESTIC WASTEWATER IN NORTHERN CLIMATES

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16. ABSTRACT

Overland flow has been demonstrated to be a feasible method for treatment of either comminuted raw sewage or primary effluent in northern climates similar to Laramie, Wyoming during the warmer seasons of the year (May through October). During the other six months of the year, the wastewater distribution system can function without freezing. However, treatment of the effluent during this colder season using an application cycle of eight hours per day, five days per week would not consistently meet discharge requirements and winter storage should be considered. Results of the research indicated that in a northerm climate up to a year is required to establish adequate vegetation on seeded plots to achieve treatment similar to that obtained from plots with established vegetation. Research of surge flow application of raw wastewater (pulsating the water using on/off cycles) significantly reduces the probability of orifice plugging.

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FOREWORD

EPA is charged by Congress to protect the Nation's land, air, and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is charged with the mission to manage research programs: to investigate the nature, transport, fate, and management of pollutants in ground water; to develop and demonstrate technologies for treating wastewater with soils and other natural systems; to control pollution from irrigated crop and animal production agricultural activities; and to develop and demonstrate cost-effective land treatment systems for the environmentally safe disposal of solid and hazardous wastes.

The purpose of this project was to demonstrate the feasibility of using one of the three major land treatment processes, overland flow, to treat both comminuted raw sewage and effluent from a primary wastewater holding lagoon in a region of low rainfall and cold climate. Data indicates that winter operation of an overland flow system using a five-day application, two-day drying cycle is not feasible in extremely cold winters typical of the study site in Laramie, Wyoming. Satisfactory wastewater treatment can be accomplished from May through October with this operation and may be extended with an alternative operation coupled with winter storage for the colder seasons. The information developed in this project will add significantly to the overland flow design criteria for winter operations.

Clinton W. Hall

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ABSTRACT

The overland flow treatment system at Laramie, Wyoming substantially treated both raw and primary municipal wastewater only during the summer months (May through October). During the cold winter months (November through April) the wastewater distribution system functioned without freezing, allowing wastewater to be applied to the plots even during the coldest weather, but treatment to discharge requirements were not met.

Plugging of the gated pipe was a major problem in applying the raw wastewater. To overcome this problem, a method of surging the water was developed. Surging pulsates the water onto the plots in a cycle of on-off times. Larger flows are used with wider gate openings. The flow resistance of the grass attentuates the waves; thus, after a short travel distance from the top of the plot, the water has a continuous flow pattern. The procedure is recommended as one method for alleviating the plugging problem when applying raw wastewater.

Treatment of the wastewater was not substantial during the cold dry winter months experienced at Laramie, Wyoming. A snow or ice pack could not be established during the fall. During the winter months, a warming period occurred that melted the ice pack. This water, along with the relatively warm wastewater, caused channels to form in the ice pack, precluding any chance of treatment during the remainder of the winter months.

Several varieties of forages were tested to find a variety that would tolerate the conditions of an overland flow site. 'Garrison' creeping meadow foxtail was the variety found to be most successful and is recommended. If the forages are seeded, it will be necessary to have at least one year to establish adequate ground cover before the treatment system will perform adequately. This time delay can be reduced if the forage is planted by sodding the area. This, however, may be costly, and the sod for the recommended variety may not be available.

Water quality and climatological data are presented in the appendices. Results from the modeling of surge flow are also presented in the appendices of this report.

This report was submitted in fulfillment of Cooperative Agreement CR 807960-01-0 by the Department of Agricultural Engineering, University of Wyoming under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 11, 1980 to September 10, 1983, and work was completed as of September 30, 1984.

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SECTION 1

INTRODUCTION

Overland flow treatment of municipal wastewater has been shown to be an economical and effective method of treating domestic wastewater. Systems such as the Werribee farm system at Melbourne, Australia (Seabrook, 1975) have demonstrated the practice over an extended period of time. With rational design procedures available (Martel, et al., 1982; Smith and Schroeder, 1983), overland flow treatment systems will be a viable alternative to be considered at many locations in the United States. The use and practicality of these systems in cold northern climates is not totally clear if year-round operation is desired. It was the main purpose of this study to develop technical data on the ability of overland flow treatment systems to treat municipal wastewater effectively in a cold, dry, northern climate.

In very cold climates wastewater can be treated by land application on a year-round basis. A study at Thayne, Wyoming concluded that a spray irrigation system operating year-round did provide treatment (Borrelli et al., 1978). Even during the winter there were significant reductions of BOD and COD in the upper soil mantle, although these decreases were probably attributable to the soil filtering the organic matter. There was, however, an indication that some biological processes were occurring during the winter. An experimental overland flow treatment system at Pauls Valley, Oklahoma operated satisfactorily during freezing winter conditions although the removal of BOD, COD, and ammonia was hampered by subfreezing temperatures (Hall et al., 1979). On the other hand, the overland flow treatment system at Hanover, New Hampshire did not satisfactorily remove BOD at soil temperatures below 4°C (Jenkins, et al., 1978). Treatment during the winter appears to be possible when the soil remains unfrozen, and a snow or ice cover can be maintained over the treatment plots while wastewater flows beneath the cover (Sabey, et al., 1981).

Because of an ice pack covering the plots and later channeling within the ice pack, the overland flow system at Laramie did not treat wastewater effectively during the cold winter months. The build-up of the ice pack did not allow water to pass beneath it; consequently, the wastewater flowed on the surface of the ice, away from the microbial population within the vegetative cover. The system did perform as expected during the warmer months. Valuable information was obtained in selecting forage species and in procedures to follow during the startup of an overland flow treatment system.

SECTION 2

CONCLUSIONS

The overland flow treatment system was marginal in achieving treatment to the minimum required discharge standards for secondary treatment. The raw wastewater plots produced effluent with BOD_5 and total suspended solids at concentrations below 30 mg/l between April and October. During the period June through October, secondary treatment standards for BOD_5 and total suspended solids were erratically met for effluent from plots receiving primary wastewater. The cause for the erratic treatment was not determined. It appears that warmer influent temperature for the raw wastewater provides for better overall treatment. Other conclusions with regard to wastewater treatment by the system are as follows:

1. Little treatment occurred during the period from November through March. Due to the dry climate, little possibility existed for creating a snow or ice cover that would last through the winter months producing a layer under which biological activity could occur.

2. For hydraulic loads of 10 cm/wk and 30 cm/wk, there was no statistically significant difference at the 0.05 level of confidence in treatment for BOD_5 and total suspended solids. This indicates that the length of the plots was great enough that treatment was not limited within the hydraulic loading rates selected for this study.

3. In a northern climate up to a year is required to establish adequate vegetation on seeded plots to achieve treatment similar to that obtained from plots with established vegetation. Concentrations were statistically significantly lower at the 0.05 level of confidence for BOD_5, NH_3-N, TSS, and TKN for effluent coming from the plot with established vegetation as compared to the seeded plot, both plots having a 20 cm/wk hydraulic loading rate.

Plugging of the distribution system was a major problem when using raw wastewater although it was passed through a communitor. A potential solution to this problem is the use of surge flow (pulsating the water using on-off cycles). The surge flow allowed large flow rates to be applied during the on-part of the cycle, thus reducing the probability for plugging. It was concluded from field testing that the retardence of the grass is sufficient to dampen out the surges so that the larger portion of the plot has essentially continuous flow. Additional conclusions about the surge flow study are as follows:

1. The 2/3 on to 1/3 off time cycle ratio is the most advantageous ratio to use when trying to simulate a continuous flow pattern in the shortest damping length possible. Field tests indicate a 10 minute on to 5 minute off cycle would be practical for overland flow wastewater treatment systems.

2. Surge flow damping to a continuous flow pattern can be attained by extending the field damping length, decreasing the loading rate, or by using a shorter cycle time.

3. Surge flow will allow automation of overland flow wastewater treatment systems by providing a dependable wastewater distribution system.

SECTION 3

RECOMMENDATIONS

The following recommendations are made with respect to overland flow wastewater treatment systems operating in a cold dry northern climate:

1. During the period May through October, raw wastewater can be successfully treated providing screening, use of surge flow, or other mechanisms are used to reduce plugging of the distribution system.

2. Primary wastewater should be handled to maintain as much of the heat as possible that it contained as raw wastewater. The added temperature will help in the treatment process, especially in the spring and fall.

3. If forages are planted in lieu of sodding, adequate time (at least one growing season) should be allowed for the forages to reach full ground cover before the treatment process begins.

4. 'Garrison' creeping meadow foxtail is recommended as the primary forage for the treatment plots. This specie, after establishment, can withstand the physical and environmental growing condition imposed by the overland flow wastewater treatment system and still produce substantial forage, remove nitrogen, and maintain full ground cover.

5. Overland flow treatment systems are not recommended if water reuse is an important consideration. The water recovery during the summer was 27 to 52 percent. Evapotranspiration used 15 to 45% of the water applied during July for this particular study. It should be noted that for this particular system, the percentage of water lost to deep percolation ranged from 37 to 57 percent. This is greater than recommended for overland flow treatment systems.

SECTION 4

MATERIALS AND METHODS

SITE DEVELOPMENT

The study site was located northwest of Laramie, Wyoming at the city's aerated lagoon wastewater treatment system. Laramie has a relatively long and severe, although dry, winter season due to its high elevation and surrounding mountain ranges. Soils adjacent to the lagoon are high in clay, and measurements showed the base infiltration rate (measured using inflow-outflow measurements on 74.4 m^2 of area) to be less than 0.3 cm/hr. A small existing reservoir having 3 days detention time was used as a primary settling pond. Fresh raw wastewater from Laramie was available adjacent to the study site. The raw wastewater was passed through a communitor.

Wastewater Distribution System

Figure 1 shows a general layout of the overland flow treatment site as it existed. Raw wastewater was taken from Laramie's wastewater line just before the wastewater enters Lagoon #3. The raw wastewater was transported by an existing 46 cm vitrified clay line to the sump area. From the sump, the raw wastewater was directed either to 1) the raw wastewater plots or to 2) the primary settling pond. The pipes leading from Laramie's wastewater lines to the overland plots were placed below the frostline while exposed gated pipe was used to apply and control the flow to each plot. Drain valves were placed in the delivery lines between the sump and settling pond and between each plot so during cold weather, these lines could be drained when the system was shutdown at the end of each day's operation during cold weather.

The primary wastewater was fed by gravity through a 10 cm PVC line to the primary wastewater plots. Gated pipe was used to control and distribute the flow to each plot. Figure 2 shows the gated pipe. The effluent from each of the plots passed through a weirbox and was then carried by a ditch system to a holding pond. The Wyoming Department of Environmental Quality required the holding pond because effluent would have passed down a drainage ditch and eventually to the Laramie River. A pump system was maintained at the holding pond to move effluent back to the city lagoon system when the holding pond was full.

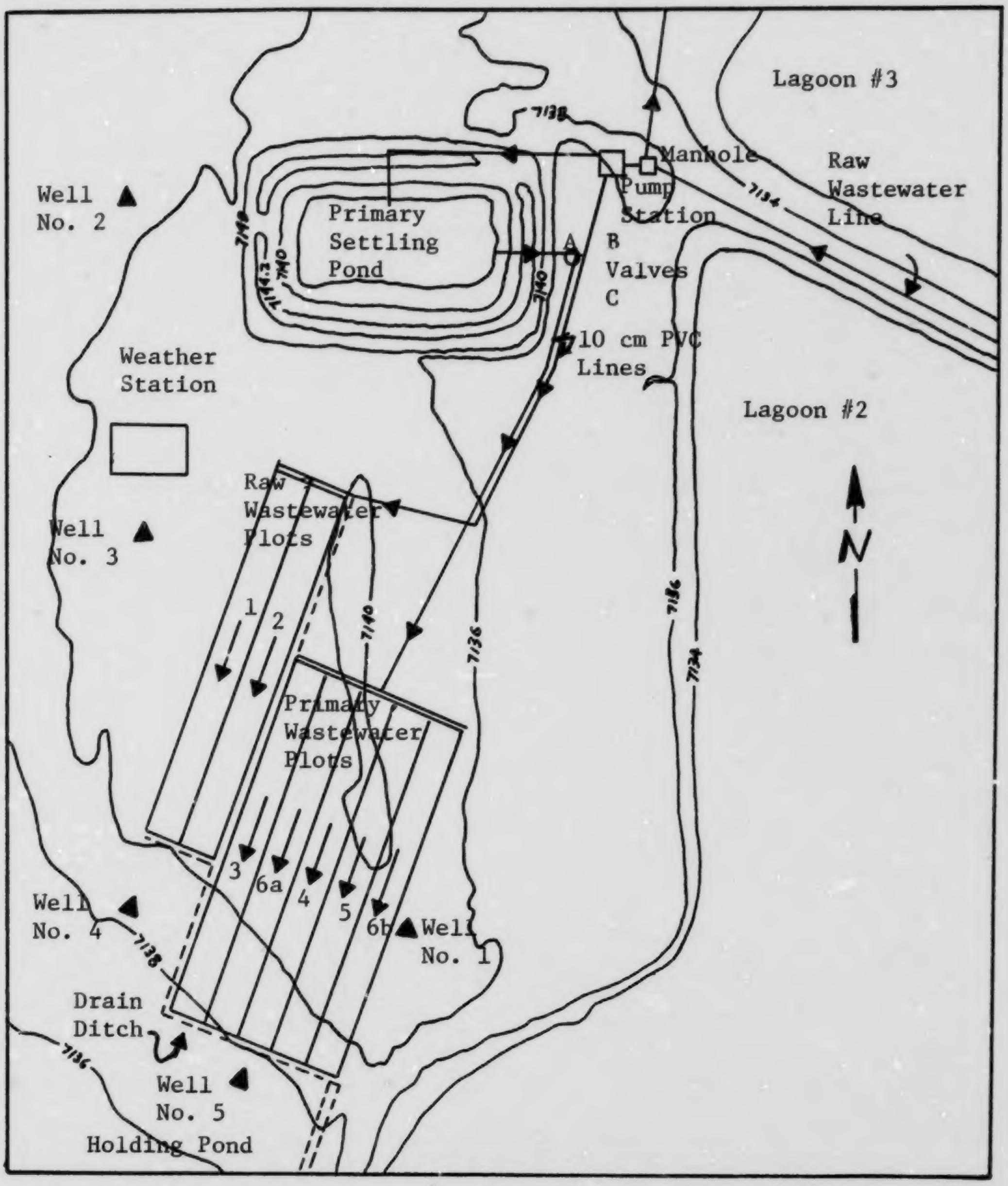
Lagoon #3
7138
Manhole
Raw
Wastewater
Line
Well
No. 2
Pump
Station
7134
Primary
Settling
Pond
7140
7141.3
A
B
Valves
C
10 cm PVC
Lines
Weather
Station
Lagoon #2
Raw
Wastewater
Plots
Well
No. 3
N
1
2
7140
7136
7136
7134
Primary
Wastewater
Plots
3
6a
4
5
6b
Well
No. 4
Well
No. 1
7138
Drain
Ditch
7136
Well
No. 5
Holding Pond

Figure 1. Detail of plot site.

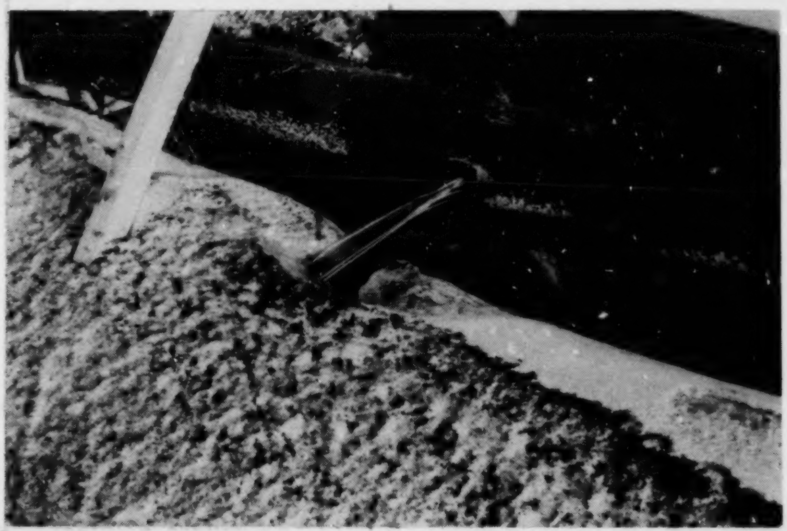

Figure 2. Gated pipe used to distribute wastewater.

The distribution system was controlled with gate valves from the sump area. The head on the primary settling pond was important in maintaining a constant flow rate to the primary plots. A staff gage was established on the pond to make sure that the pond level stayed approximately at the same elevation (±5 cm) during operation.

The actual construction of the distribution system's lines was begun in February 1981. The system was essentially operational in March 1981, but operation was delayed due to the Wyoming Department of Environmental Quality's requirement of a holding pond for the effluent from the plots. The raw wastewater line was not finished and put into operation until August 1981. During the interim period between April and August, lagoon water was used to test the system's operation and establish the grass plots.

The gated pipe was installed on a support system, with concrete pillars placed in the ground below the frostline to prevent movement during the winter period. The gated pipe was painted black. A plastic windbreak was built over the gated pipe in an attempt to minimize freezing problems during winter operation. Figure 3 shows the windbreak.

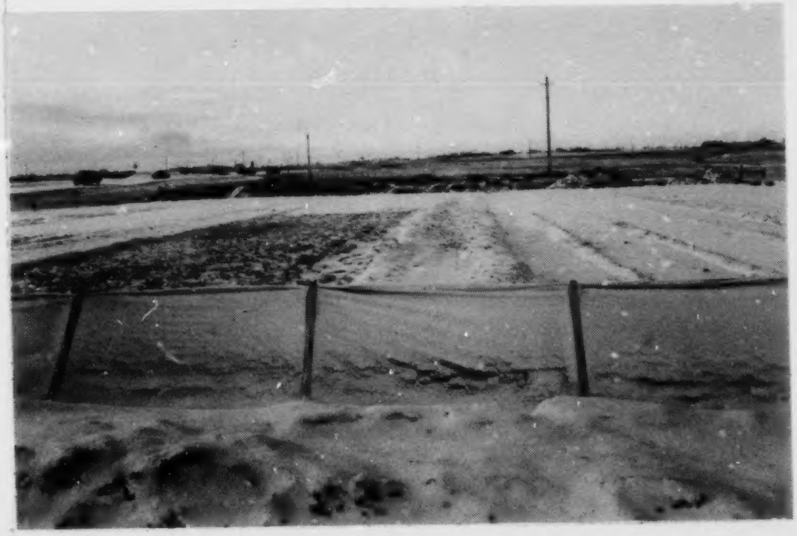

Figure 3. Plastic windbreak for gated pipe.

Overland Flow Plots

Seven overland flow plots were constructed at the site (Figure 1). Table 1 gives the dimensions and slopes of each plot, along with the target hydraulic loading rates. Two plots (plots 1 and 2) were treated directly with raw wastewater, and the other five plots were treated with primary wastewater.

The initial construction of the plots occurred during October and November of 1980, and a fence was placed around the plots. This allowed the plots to settle during the winter season so that they could be graded and planted the following spring. The plots were regraded during April and May of 1981. Fertilizer was placed on the plots (90 Kg/ha of nitrogen and 112 Kg/ha of phosphorus), and the plots were then rototilled and reshaped for the placement of sod and the seeding of selected grasses in plots 6A and 6B (Figure 1). The seeded plots were subdivided into four subplots and planted with eight different grass species.

A number of individual plants, started in the greenhouse were transplanted at the top of each subplot. In the sodded plots (Numbers 1, 2, 3, 4, and 5 in Figure 1), a sedge-rush sod was transplanted during May and June of 1981. The area was kept wet, initially by sprinkling, and later by the use of the delivery system.

TABLE 1. PLOT PARAMETERS

Plot No.	Type of Effluent	Length (m)	Width (m)	Slope (%)	Hydraulic Loading (cm/week)	Application Rate (m^3/m-hr)	Operation time	
							(hrs/day)	(days/week)
1	Raw	60	9.1	1.3	15	0.22	8	5
2	Raw	60	8.2	1.3	10	0.15	8	5
3	Primary	61	6.4	1.6	30	0.46	8	5
4	Primary	62	6.7	1.6	20	0.31	8	5
5	Primary	62	6.7	1.6	15	0.23	8	5
6A	Primary*	62	6.7	1.5	20	0.31	8	5
6B	Primary**	61	6.7	1.5	20	0.30	8	5

BIOLOGICAL AND CHEMICAL ANALYSES

The principal biological and chemical parameters that were evaluated were those used to characterize performance. The parameters are listed in Table 2. Influent and effluent were sampled once every two weeks. One sample was taken from the primary wastewater, one sample from raw wastewater, and one sample from the effluent of each plot during peak runoff. Grab samples were taken from the observation wells once each month (Figure 1) and were analyzed for the parameters indicated in Table 2.

TABLE 2. WASTEWATER PARAMETERS THAT WERE MONITORED

Biochemical Oxygen Demand (BOD_5)	Fecal Coliform
Chemical Oxygen Demand (COD)	pH*
Total Organic Carbon (TOC)*	Dissolved Oxygen* (DO)*
Volatile Solids	Nitrate (NO_3)*
Total Suspended Solids (TSS)	Ammonia (NH_3-N)
Total Kjeldahl Nitrogen (TKN)*	Temperature*
Total Phosphorus (T-P)*	
Ortho-phosphorus (O-P)*	
Specific Conductance*	

*Parameter analyzed for the well water samples.

HYDRAULIC FLOW RATES

The system was designed to apply water at the hydraulic loading rates given in Table 1. To accomplish this, the system was normally operated eight hours per day, five days per week. Water was distributed to the plots through gated pipe.

The primary wastewater was distributed to the plots by gravity. A constant head was obtained by maintaining a uniform water surface elevation in the primary settling pond (Figure 1). Replacement water was pumped to the pond whenever water was applied to the plots. To insure proper gate settings on the gated pipe (for quality control purposes), flow rates were periodically calibrated with a constant head orifice can or by weight-time measurements. The outlets were checked every day for any material that may have caused plugging; this material was removed.

The raw wastewater was pumped directly to the plots and distributed by gated pipe. To maintain a constant discharge, an overflow pipe was set at a given elevation. Excess water was pumped so that water was always discharging from the overflow pipe. The gates were calibrated and maintained just as for the primary plots.

Water meters were placed in the main line to record the volume of water being delivered to the plots. However, although the outlets were checked daily, plugging problems persisted and the data were unreliable.

AGRONOMIC STUDY

The experience with a year-round land treatment system at Thayne, Wyoming pointed out the need to select a forage that can survive not only heavy application of water, but winter ice conditions, as well (Borrelli, et al., 1978). To be able to recommend a forage that can be used on overland flow systems in cold northern climates, several different varieties of forages were tested for survival. Table 3 lists the varieties tested.

TABLE 3. SPECIES OBSERVED FOR VIABILITY

Common Name	Scientific Name
'Garrison' creeping meadow foxtail	Alopecurus anundinaceus
Reed canarygrass	Phalaris arundinacea
Western wheatgrass	Agropyron smithii
Timothy 'Hopkin'	Phleum pratense
Tall fescue 'Fawn'	Festuca arundinacea
'Manchar' smooth broomgrass	Bromus inermis
Redtop grass	Agrostis alba
Alsike clover	Trifolium hybridum

The seeded plots were each divided into four subplots and the grass species listed in Table 3 were planted during July, 1981. Table 4 lists the seeding rates. At the top of each subplot, 36 individual plants which had been started in the greenhouse were transplanted. This was so survival rates could be determined. The area was kept wet, initially by sprinkling primary wastewater, and later by the use of the delivery system.

TABLE 4. SEEDING RATES OF PLANTED SPECIES

Specie	Seeding rate (kg/ha)
'Garrison' creeping meadow foxtail	6.7
Reed canarygrass	6.7
Western wheatgrass	11.2
Timothy 'Hopkin'	5.6
Tall fescue 'Fawn'	7.9
'Manchar' smooth brome grass	9.0
Red top grass	5.4
Alsike clover	4.5

The primary test parameter was viability. For those species surviving the field conditions into the third year, forage production was analyzed.

Sod cut from an existing mountain meadow was used to establish all plots except 6A and 6B (Figure 1). The sod consisted of a sedge-rush mixture that had been interseeded with 'Garrison' creeping meadow foxtail. Table 5 shows composition of the sod.

TABLE 5. SPECIE COMPOSITION OF SOD

Common Name	Scientific Name
Rush (≅40%)	Juncus spp.
Sedge (≅40%)	Canex spp.
Dandelion (≅5%)	Tanaxacum officinale
'Garrison' creeping meadow foxtail (≅10%)	Alopecurus Anundinaceus
Foxtail barley (≅5%)	Hordeum jubatum

SECTION 5

RESULTS AND DISCUSSION

WINTER-TIME OPERATION AND PROBLEMS

The system operated without any freezing problems throughout the duration of this project. However, a minor problem occurred due to the ice buildup in the settling pond during the winter. The ice depth continued to increase from month to month, making it increasingly difficult to keep the water in the pond at the desired level. This was because a larger and larger percentage of the volume below the desired level was being filled by ice.

Although the wastewater distribution system operated during cold weather without any problems, winter operation led to a number of problems with the ice pack and wastewater treatment. Ice pack formation began near the lower ends of the plots. Once the ice packs started to form, they continued to develop with water flowing over the top and freezing. For treatment, it would have been desirable for the wastewater to flow beneath the ice packs. This did not happen consistently. The water which did flow under the ice packs generally channeled its way through the packs instead of spreading out uniformly over the soil (Figure 4). In addition, the ice pack formation did not occur over the entire plots. Measurements of ice depths during much of the 1982-1983 winter are given in Table 6, while the average depths for each date are plotted on Figure 5. As the ice packs grew, the depth on the lower ends of the plots reached a level that was greater than the height of the berms separating the plots. Thus, the ice packs merged with those of adjacent plots, forming a single sheet of ice which reached a depth of as much as 40 cm on the primary plots. When this occurred, wastewater flowed over or through the berms between plots. The ice depths on the raw plots were not as great as those on the primary plots, apparently due to the higher influent temperature for the raw plots. In general, the method of ice pack formation and the tendency for channeling to occur seriously affected treatment.

SYSTEM PERFORMANCE

All water quality data collected to evaluate the performance of the system are given in Appendix A. Well No. 4 was dry so data for that site is not in the appendix. Data were normally collected every two weeks from July 1981 through July 1983. The water quality data included samples of the applied raw and primary wastewater and the effluent from each plot, with the data from the two seeded plots being treated as a single plot (Table 1). Duplicate samples were taken on various plots at fixed intervals.

The water quality parameters discussed herein are limited to TKN, ammonia-N, total phosphate as PO_4, BOD_5 and total suspended solids (TSS). Most of the results are grouped into one-month monitoring periods. However, the periods are not precisely one-month periods since samples were taken every two weeks. Thus each sample was included in the month in which the

TABLE 6. DEPTH OF ICE ON THE PLOTS (cm)

	Plot	Distance from top of plot (m)								
		6.1	12.2	18.3	24.4	30.5	36.6	42.7	48.8	54.9
12-16-82	1	5	10	5	5	5	8	5	13	8
	2	5	10	5	10	10	10	10	13	15
	3	8	3	5	5	10	15	13	15	15
	4	0	3	5	3	5	8	10	10	10
	5	0	3	8	5	10	13	6	10	13
	6A	0	0	5	5	5	8	13	13	15
	6B	0	5	8	3	3	5	10	13	15
	Avg	2.6	4.9	5.9	5.1	6.9	9.6	9.6	12.4	13.0
1-13-83	1	0	0	0	3	0	8	10	13	8
	2	0	0	5	0	15	13	13	13	15
	3	3	3	10	13	20	20	20	23	30
	4	3	3	5	13	13	25	28	30	33
	5	0	0	13	18	20	23	23	28	28
	6A	8	10	15	18	23	28	33	33	36
	6B	0	0	3	8	10	18	20	20	23
	Avg	2.0	2.3	7.3	10.4	14.4	19.3	21.0	22.9	24.7
1-27-83	1	0	0	0	8	0	8	8	10	5
	2	0	0	0	0	13	13	13	10	15
	3	0	3	8	13	15	20	23	30	36
	4	0	0	8	18	18	33	36	38	38
	5	0	0	10	15	18	25	28	30	30
	6A	4	10	15	15	20	23	36	38	38
	6B	0	0	0	5	10	15	20	20	23
	Avg	0.6	1.9	5.9	10.6	13.4	19.6	23.4	25.1	26.4
2-10-83	1	0	0	0	5	5	8	8	10	8
	2	5	5	5	5	15	13	13	10	15
	3	0	3	8	10	20	18	20	25	30
	4	0	0	10	20	25	30	36	38	43
	5	0	0	10	14	15	28	33	38	36
	6A	5	10	15	18	23	27	33	37	41
	6B	0	0	8	10	10	18	20	22	25
	Avg	1.4	2.6	8.0	11.7	16.1	20.3	23.3	25.7	28.3
2-24-83	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	5	6	8	10
	3	0	0	5	5	15	15	18	33	36
	4	0	0	15	18	20	36	36	38	38
	5	0	0	0	10	15	25	30	36	33
	6A	0	0	10	13	15	23	33	36	41
	6B	0	0	0	5	5	14	14	20	23
	Avg	0	0	4.3	7.3	10.0	16.9	19.6	24.4	25.9
3-10-83	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	10	15	28	28
	4	0	0	0	8	13	28	33	34	36
	5	0	0	0	0	5	15	18	23	23
	6A	0	0	0	0	8	13	20	23	28
	6B	0	0	0	5	5	13	15	20	23
	Avg	0	0	0	1.9	4.4	11.3	14.4	18.3	19.7

TABLE 6. (cont.)

		6.1	12.2	18.3	24.4	30.5	36.6	42.7	48.8	54.9
3-24-83	1									
	2									
	3	0	0	0	0	0	0	0	13	18
	4	0	0	0	0	0	15	15	20	23
	5	0	0	0	0	0	0	0	5	18
	6A	0	0	0	0	0	5	10	13	15
	6B	0	0	0	0	0	0	5	5	8
	Avg	0	0	0	0	0	2.9	4.3	8.0	11.7
4-7-83	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	5	15	18
	4	0	0	0	0	0	15	13	18	18
	5	0	0	0	0	0	0	0	5	15
	6A	0	0	0	0	0	3	5	8	8
	6B	0	0	0	0	0	0	0	5	5
	Avg	0	0	0	0	0	2.6	3.3	7.3	9.1

greatest portion of the two week sample period occurred (Table 7). This grouping permits some reduction of the data yet still retains the seasonal characteristics of the results. The study was interrupted for over a month during the early spring of 1982 due to construction on the Laramie wastewater lagoons.

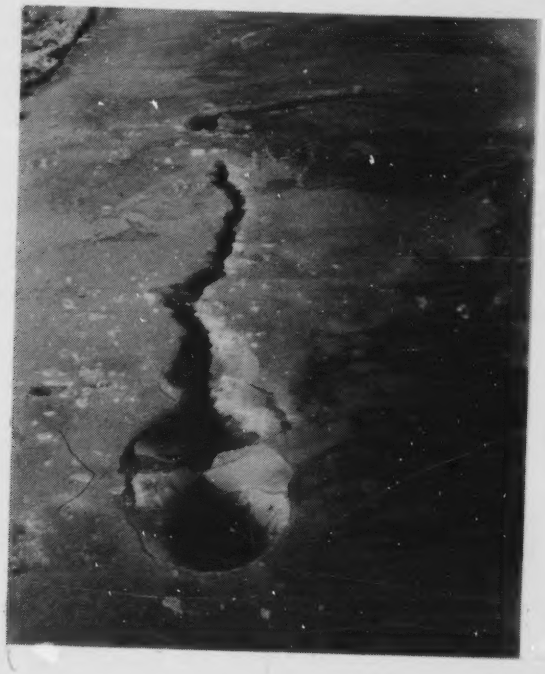

Figure 4. Channelization of flow under the ice pack.

Table 7 gives a summary of the air temperature and precipitation for each one-month period. The monthly average temperatures of the effluents and of the raw and primary wastewaters are also given. Daily temperatures and precipitation during the entire test period are given in Appendix B. Tables 8 through 12 give the treatment results on the basis of actual comparative concentrations in the influent and effluents.

Treatment Efficiency

The system was only marginal in achieving the minimum required discharge standards for secondary treatment. Summer treatment was generally greater than achieved during winter; however, considerable differences existed between treatment obtained on the raw plots and the primary plots. This was especially true in the case of BOD_5.

Concentration levels of BOD_5 for effluents from Plots 1 and 2 were below or near 30 mg/l for most months between April and October (Table 10). This

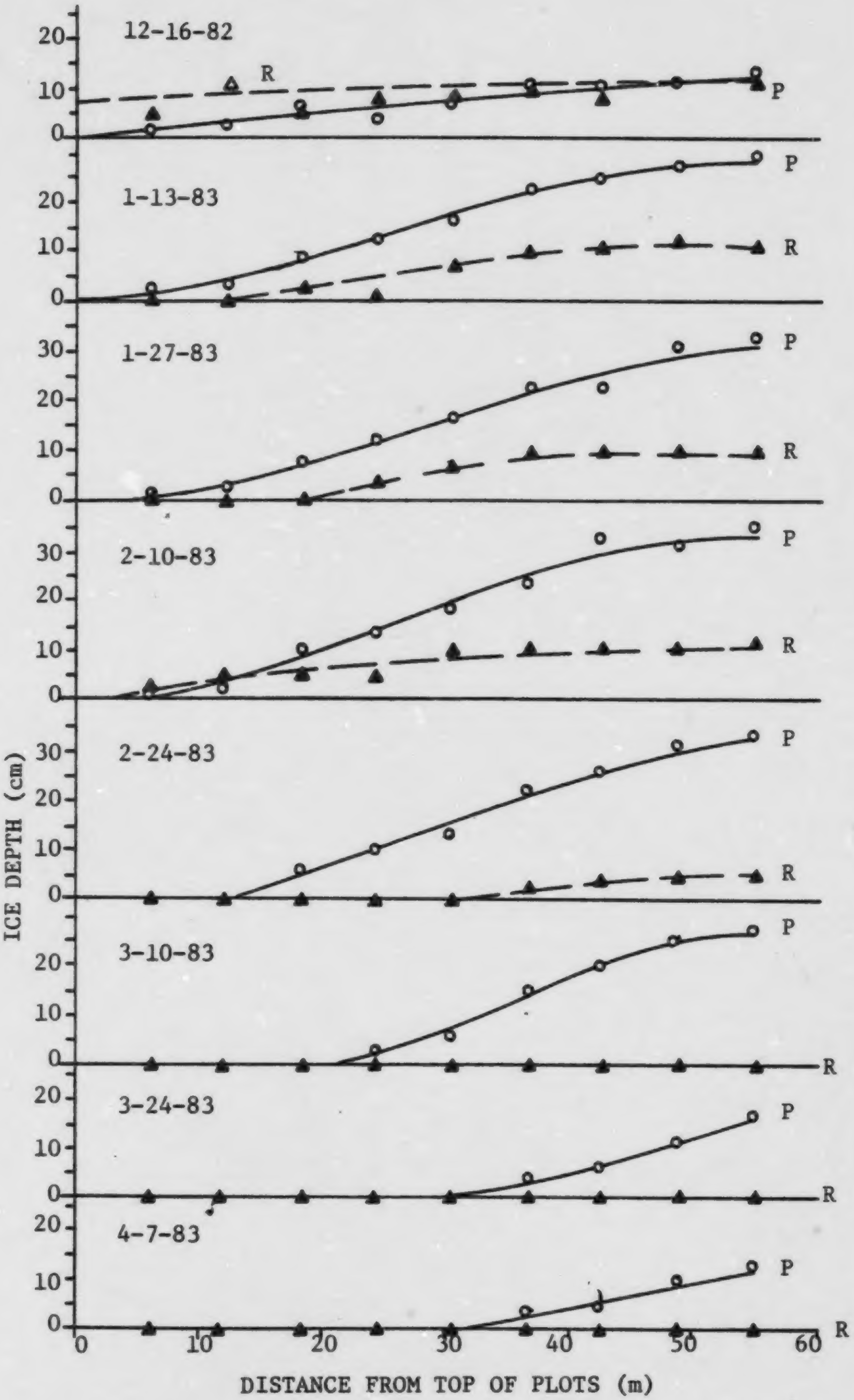

Figure 5. Ice depths averaged for the raw (R) and primary (P) plots on the dates indicated.

TABLE 7. PRECIPITATION AND AVERAGE TEMPERATURES

Date	Total Precipitation (cm)	Avg. Air Temp (°C)	Wastewater Temperature (°C)								
			Influent		Effluent						
			Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	4.16	17.77	19.0	19.0	19.0	18.0	18.0	18.0	18.0	20.0	18.5
Aug 81	3.70	13.37	18.0	16.5	15.0	-99.0	16.0	19.5	19.5	22.0	18.4
Sep 81	2.13	10.77	18.5	17.0	15.0	13.0	13.3	15.5	14.0	21.5	15.4
Oct 81	3.07	1.71	15.3	8.0	5.5	6.0	4.8	5.9	7.0	8.5	6.3
Nov 81	.89	.90	12.0	3.5	1.5	1.5	.5	.5	.5	.5	.8
Dec 81	1.66	-7.74	11.3	4.3	.5	1.0	.2	0	0	0	.3
Jan 82	.89	-8.11	11.5	5.3	1.0	1.0	1.0	1.5	1.0	1.0	1.1
Feb 82	.48	-2.94	10.5	4.5	.3	0	.3	.5	.5	1.0	.4
Mar 82	1.18	-2.09	11.0	6.0	5.0	3.0	4.0	4.0	4.5	7.0	4.6
Apr 82	1.68	4.14	13.5	10.0	11.0	10.0	10.0	10.0	-99.0	11.0	10.4
May 82	5.38	6.90	12.5	11.8	15.5	15.5	15.3	15.5	15.3	18.5	15.9
Jun 82	3.64	12.41	17.0	17.0	19.1	19.0	19.5	18.5	16.5	23.3	19.3
Jul 82	4.99	17.61	19.5	20.8	24.0	23.4	23.3	24.0	25.5	28.5	24.8
Aug 82	4.72	16.75	21.5	18.8	20.0	19.2	19.0	17.0	16.3	20.5	18.7
Sep 82	4.84	8.26	16.5	12.5	11.1	11.0	9.0	10.0	10.8	11.0	10.5
Oct 82	2.38	1.82	14.0	7.5	6.3	6.0	6.3	6.0	5.4	7.5	6.3
Nov 82	2.95	-4.75	12.7	5.3	3.2	2.0	1.3	1.7	1.3	2.7	2.0
Dec 82	1.78	-4.26	10.5	4.8	.5	0	.5	0	0	0	.2
Jan 83	.34	-6.93	10.8	6.8	2.0	1.8	2.0	2.5	2.5	2.5	2.2
Feb 83	2.43	-2.65	10.5	5.4	1.0	1.0	3.5	2.5	1.0	1.5	1.8
Mar 83	3.22	-5.71	10.7	7.2	6.0	4.3	2.8	6.0	1.7	1.8	3.8
Apr 83	9.01	-.56	10.5	9.0	7.5	7.8	8.7	7.5	6.0	7.5	7.5
May 83	5.90	5.81	12.0	10.5	12.4	13.5	12.8	12.9	11.5	13.0	12.7
Jun 83	1.80	13.03	16.0	16.5	19.6	20.5	21.3	21.0	21.0	20.4	20.6
Jul 83	3.80	16.03	19.5	21.0	22.8	22.0	22.5	24.0	23.0	24.0	23.0

Note: -99 represents missing data.

TABLE 8. AVERAGE NH_3-N DURING ONE MONTH PERIODS (MG/L)

Date	Influent		Effluent						
	Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	15.5	15.0	12.5	11.0	9.2	7.5	3.9	10.0	9.0
Aug 81	35.0	9.8	2.9	-99.0	10.0	4.4	3.9	11.3	6.5
Sep 81	25.0	21.5	21.0	15.5	10.1	10.1	10.0	9.6	12.7
Oct 81	25.0	21.0	10.8	7.6	9.7	11.4	11.0	24.5	12.5
Nov 81	23.8	21.0	19.3	20.3	18.5	19.5	13.4	20.5	18.6
Dec 81	21.5	21.0	15.3	18.0	20.3	20.3	21.0	22.5	19.6
Jan 82	22.8	22.3	23.5	23.0	21.5	21.0	21.8	21.5	22.1
Feb 82	22.5	22.0	20.0	20.0	21.3	21.5	15.5	20.0	19.7
Mar 82	19.0	21.5	18.0	16.0	18.0	18.0	19.0	21.0	18.3
Apr 82	22.5	28.0	22.0	17.0	16.0	14.0	-99.0	22.0	18.2
May 82	19.3	18.5	12.9	13.1	6.9	5.4	8.4	12.5	9.9
Jun 82	19.0	13.0	3.5	6.5	5.5	4.4	.7	4.8	4.2
Jul 82	22.3	13.0	9.2	8.1	9.6	8.1	8.6	8.6	8.7
Aug 82	29.0	12.5	6.6	4.0	9.2	4.2	1.2	4.1	4.9
Sep 82	25.8	19.5	8.4	5.1	12.7	10.0	4.4	14.0	9.1
Oct 82	27.3	19.3	9.6	7.5	8.1	12.0	4.3	15.5	9.5
Nov 82	26.3	20.7	16.5	14.4	17.0	15.8	13.2	18.5	15.9
Dec 82	21.8	22.3	18.8	20.5	26.5	24.0	24.5	26.5	23.5
Jan 83	24.5	24.5	22.8	23.3	22.7	22.8	23.0	24.5	23.2
Feb 83	32.5	24.5	18.3	22.0	23.0	22.0	20.8	20.3	21.1
Mar 83	20.2	20.0	18.3	16.0	17.3	18.8	17.3	18.7	17.7
Apr 83	17.5	15.0	10.1	7.6	9.7	11.1	6.9	13.0	9.7
May 83	13.0	11.3	3.8	1.7	2.2	2.6	3.2	3.0	2.8
Jun 83	15.3	9.6	5.6	3.3	1.5	2.1	2.1	1.8	2.7
Jul 83	15.5	6.9	4.6	4.1	2.5	3.2	1.0	1.0	2.7

Note: -99 represents missing data.

TABLE 9. AVERAGE TKN DURING ONE MONTH PERIODS (MG/L)

Date	Influent		Effluent						
	Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	20	18	14	14	13	11	6	14	12
Aug 81	40	25	5	-99	11	5	5	15	8
Sep 81	39	35	23	17	13	15	14	21	17
Oct 81	34	29	15	13	14	15	13	30	16
Nov 81	35	29	24	26	22	22	18	27	23
Dec 81	34	28	21	25	27	26	27	28	25
Jan 82	37	29	34	34	29	27	28	26	29
Feb 82	35	30	32	30	29	29	23	29	29
Mar 82	30	27	23	23	22	23	23	26	23
Apr 82	32	28	22	17	20	17	-99	26	20
May 82	28	26	15	15	15	14	15	19	15
Jun 82	28	21	9	12	11	9	8	13	10
Jul 82	29	20	13	15	15	14	18	14	15
Aug 82	34	19	9	23	16	8	6	10	12
Sep 82	30	23	12	12	14	12	7	17	12
Oct 82	32	24	14	11	14	16	9	18	14
Nov 82	34	25	19	17	20	19	17	22	19
Dec 82	33	28	23	26	31	28	29	31	28
Jan 83	36	27	27	30	25	26	25	26	26
Feb 83	34	26	21	25	25	24	24	25	24
Mar 83	29	24	22	18	21	22	21	22	21
Apr 83	25	22	15	13	13	15	12	17	14
May 83	21	19	8	12	9	9	10	10	10
Jun 83	22	15	9	6	4	6	7	8	6
Jul 83	25	14	8	7	6	7	6	5	6

Note: -99 represents missing data.

TABLE 10. AVERAGE BOD$_5$ DURING ONE MONTH PERIODS (MG/L)

Date	Influent		Effluent						
	Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	64	49	32	35	23	24	19	32	27
Aug 81	118	70	13	-99	58	39	33	71	43
Sep 81	108	90	36	8	24	17	12	57	25
Oct 81	124	83	20	21	33	37	35	53	33
Nov 81	138	90	46	49	57	58	52	76	56
Dec 81	118	125	70	108	95	94	98	115	96
Jan 82	143	118	87	120	94	92	99	105	99
Feb 82	145	125	115	101	113	109	93	103	106
Mar 82	100	110	62	62	64	71	63	70	65
Apr 82	190	88	28	23	56	58	-99	68	47
May 82	126	480	29	26	52	65	61	74	51
Jun 82	170	64	13	18	36	33	36	39	29
Jul 82	178	59	33	41	34	33	47	33	36
Aug 82	120	93	22	62	43	31	35	44	40
Sep 82	122	70	41	31	47	41	31	50	40
Oct 82	143	68	28	27	55	44	38	42	39
Nov 82	143	94	34	40	58	61	52	63	51
Dec 82	140	113	58	73	108	102	104	104	91
Jan 83	223	119	78	87	89	89	95	91	88
Feb 83	210	148	118	115	130	120	117	121	120
Mar 83	132	96	63	38	63	64	65	56	58
Apr 83	93	81	27	30	48	51	41	50	41
May 83	109	95	25	29	52	55	41	57	43
Jun 83	102	45	16	17	17	22	18	24	19
Jul 83	104	59	18	11	10	10	15	15	13

Note: -99 represents missing data.

TABLE 11. AVERAGE TOTAL SUSPENDED SOLIDS DURING ONE MONTH PERIODS (MG/L)

Date	Influent		Effluent						
	Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	8	16	8	6	4	4	12	20	9
Aug 81	38	15	2	-99	12	7	3	21	9
Sep 81	42	25	7	0	15	6	8	22	10
Oct 81	51	15	6	6	13	6	22	32	14
Nov 81	63	14	27	27	10	90	58	16	38
Dec 81	80	25	10	25	17	13	19	26	18
Jan 82	122	36	87	78	49	23	51	97	64
Feb 82	87	23	20	68	22	35	48	117	51
Mar 82	40	26	16	73	18	16	17	46	31
Apr 82	88	22	1	0	6	2	-99	65	15
May 82	89	28	3	4	14	13	15	28	13
Jun 82	60	26	9	39	3	8	95	14	28
Jul 82	67	42	22	43	16	34	115	16	41
Aug 82	54	40	18	295	26	14	278	24	109
Sep 82	59	25	352	186	11	37	10	12	101
Oct 82	39	29	73	102	53	17	27	17	48
Nov 82	23	10	23	12	9	6	7	14	12
Dec 82	61	11	7	11	12	13	24	13	13
Jan 83	68	16	44	21	21	15	127	19	41
Feb 83	53	11	12	7	15	11	9	10	10
Mar 83	57	23	42	11	23	42	49	9	29
Apr 83	32	15	46	47	10	15	12	10	23
May 83	13	10	117	90	3	4	60	7	47
Jun 83	24	11	19	9	8	8	13	7	11
Jul 83	41	22	2	0	1	2	43	4	9

Note: -99 represents missing data.

TABLE 12. AVERAGE TOTAL PHOSPHATE (T-P) DURING ONE MONTH PERIODS (MG/L)

Date	Influent		Effluent						
	Raw	Primary	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Avg.
Jul 81	18	18	10	12	12	10	4	13	10
Aug 81	18	15	5	-99	10	5	5	9	7
Sep 81	19	27	13	9	10	9	9	12	10
Oct 81	19	19	12	11	13	13	14	18	13
Nov 81	20	21	16	18	16	15	17	18	16
Dec 81	17	18	17	22	19	17	19	17	18
Jan 82	21	17	17	18	17	13	17	17	16
Feb 82	18	18	22	16	17	17	16	17	17
Mar 82	21	19	20	21	17	18	23	21	20
Apr 82	21	21	14	12	16	14	-99	19	15
May 82	21	21	15	14	17	17	15	15	15
Jun 82	19	17	13	15	14	13	11	10	12
Jul 82	19	17	15	18	15	15	15	15	15
Aug 82	17	16	10	19	14	12	11	14	13
Sep 82	21	16	15	14	15	14	12	17	14
Oct 82	19	19	20	18	21	19	18	21	19
Nov 82	20	19	16	18	17	18	15	18	17
Dec 82	21	22	16	20	21	19	21	21	19
Jan 83	19	18	16	16	19	18	18	19	17
Feb 83	17	16	14	16	16	15	17	17	15
Mar 83	17	17	17	17	19	21	17	18	18
Apr 83	11	12	12	12	10	10	10	10	10
May 83	11	12	9	12	10	10	9	9	10
Jun 83	13	11	10	9	10	11	10	10	10
Jul 83	12	9	8	7	10	9	9	9	9

Note: -99 represents missing data.

was true for all three summers of operation, including the first months immediately after startup of the system. BOD_5 concentrations for effluent from the plots receiving primary wastewater were seldom below 30 mg/l. An exception is that during the last two months (June and July of 1983) of operation of the system, the BOD_5 levels for effluent from all the plots were below 30 mg/l. A possible explanation for the lower BOD_5 levels for the effluent from the plots receiving raw wastewater is that during most of the year the temperature of the raw wastewater influent was greater than for the primary wastewater influent. This was especially apparent during winter and early spring. As explained earlier, this temperature effect was great enough to limit ice pack buildup on the raw plots as compared to the primary plots.

For most months, total suspended solids concentrations were below 30 mg/l for all plots. However, there were a number of months in which the suspended solids concentrations of the effluents exceeded 30 mg/l. These appear to occur more or less randomly.

Except for the last three months of operation, NH_3-N levels were nearly all greater than 4 mg/l (Table 8). However, during the last three months, May through July of 1983, all effluents were below or near the 4 mg/l discharge limit.

Seeded vs Sodded Plots

The relative wastewater treatment efficiencies of the seeded and sodded plots can be analyzed by comparing plot 6 (seeded) with the other five plots (sodded). However, the best comparisons can be made between plot 6 and plot 4 since the hydraulic loading rates of these two plots were the same (20 cm/wk) and primary wastewater was applied to both plots. Summaries of comparisons of the plots are given in Table 13 for the summer months and Table 14 for the entire year. In both cases, effluent from plot 6 had higher concentrations for all parameters than effluent from plot 4. The summer concentrations were significantly lower at the 0.05 level for plot 4 effluent for BOD_5, NH_3-N, suspended solids, and TKN as compared to plot 6. Although not tested statistically, there appeared to be greater differences during 1982 than during 1983, that is, while vegetation was still being established on the seeded plot. In any case, the implications from this study are that treatment will not be as good on seeded plots during the first year or two of establishment as on plots already having established vegetation.

Seasonal Performance

Design of an overland flow system for a dry northern climate similar to Laramie's requires a wastewater storage facility during the winter months. For example, in this study little treatment occurred for a period of about 180 days. Table 15 shows wastewater effluent temperatures from plot 1 and air temperatures. Measured effluent temperatures were below 10°C from mid-October through April of each year. Martel et al. (1982) have shown that a reduction in BOD_5 removal efficiency can be expected as surface soil temperatures drop below 10°C, and that improved nitrogen removal is expected as temperature increases. Ketchum and Cunningham (1983) have shown that an active microbial population can be developed on overland flow plots under severe winter conditions. However, treatment occurred only on those portions of plots that

TABLE 13. COMPARISON OF AVERAGE EFFLUENT QUALITY FOR THE SIX PLOTS DURING THE MONTHS MAY THROUGH OCTOBER

Temperature	Plot	Mean (° C)
	6	18.4 a*
	4	16.0 b
	1	15.8 b
	2	15.6 b
	3	15.5 b
	5	14.1 b

NH_3-N	Plot	Mean (mg/1)
	6	9.3 a
	1	8.6 ab
	3	7.5 ab
	2	7.3 ab
	4	6.6 bc
	5	4.8 c

TKN	Plot	Mean (mg/1)
	6	14.9 a
	2	13.1 ab
	3	11.9 bc
	1	11.8 bc
	4	10.8 bc
	5	9.5 c

BOD_5	Plot	Mean (mg/1)
	6	45.5 a
	3	37.2 ab
	4	34.7 bc
	5	32.4 bcd
	2	27.2 cd
	1	25.1 d

Total Suspended Solids	Plot	Mean (mg/1)
	2	65.0 a
	5	53.9 ab
	1	49.1 ab
	6	17.2 ab
	3	13.8 b
	4	12.3 b

Total Phosphates	Plot	Mean (mg/1)
	6	13.2 a
	3	13.2 a
	2	13.2 a
	4	12.1 ab
	1	11.9 ab
	5	10.9 b

*Means followed by the same letter are not significantly different at the 5% probability level.

TABLE 14. COMPARISON OF AVERAGE EFFLUENT QUALITY FOR THE SIX PLOTS DURING THE ENTIRE YEAR

Temperature	Plot	Mean (°C)
	2	13.2 a*
	6	11.0 a
	1	9.8 a
	4	9.8 a
	3	9.4 a
	5	9.3 a
NH_3-N	Plot	Mean (mg/1)
	6	14.8 a
	1	13.4 ab
	3	13.2 b
	2	12.7 b
	4	12.6 b
	5	10.8 c
TKN	Plot	Mean (mg/1)
	6	20.0 a
	2	18.4 ab
	3	17.6 b
	1	17.5 b
	4	16.8 bc
	5	15.4 c
BOD_5	Plot	Mean (mg/1)
	4	78.0 a
	6	64.5 ab
	3	58.4 ab
	5	54.2 ab
	2	48.8 b
	1	44.5 b
Total Suspended Solids	Plot	Mean (mg/1)
	2	48.2 a
	5	46.7 a
	1	38.9 ab
	6	26.6 ab
	4	17.6 b
	3	15.6 b
Total Phosphates	Plot	Mean (mg/1)
	6	15.4 a
	2	15.2 ab
	3	15.0 ab
	4	14.1 bc
	1	14.1 bc
	5	13.8 c

*Means followed by the same letter are not significantly different at the 5% probability level.

TABLE 15. AVERAGE AIR TEMPERATURE FOR PERIOD TWO WEEKS BEFORE SAMPLE DATES AND WASTEWATER EFFLUENT TEMPERATURES ON THE SAMPLE DATES FOR PLOT 1

Date	Average Air Temperature (°C)	Wastewater Effluent Temperature for Plot 1 (°C)
Aug 6, 1981	19	19
Sep 3, 1981	13	15
Sep 17, 1981	12	16
Oct 6, 1981	9	14
Oct 22, 1981	7	6
Nov 5, 1981	0	5
Nov 19, 1981	2	3
Dec 3, 1981	-1	0
Dec 17, 1981	-1	0
Dec 30, 1981	-9	1
Jan 14, 1982	-11	1
Jan 28, 1982	-5	1
Feb 11, 1982	-16	0
Feb 25, 1982	1	0
Mar 11, 1982	-2	5
May 6, 1982	0	11
May 20, 1982	5	14
Jun 3, 1982	8	17
Jun 17, 1982	9	20
Jul 15, 1982	14	18
Aug 5, 1982	18	22
Sep 2, 1982	17	20
Sep 16, 1982	10	15
Sep 30, 1982	9	8
Oct 14, 1982	3	10
Oct 28, 1982	4	3
Nov 10, 1982	-1	6
Nov 18, 1982	-4	3
Dec 2, 1982	-6	0
Dec 16, 1982	-6	1
Dec 30, 1982	-2	0
Jan 13, 1983	-2	2
Jan 27, 1983	-6	2
Feb 10, 1983	-8	0
Feb 24, 1983	-4	2
Mar 10, 1983	-2	8
Mar 24, 1983	-4	7
Apr 7, 1983	-7	3
Apr 21, 1983	-4	2
May 5, 1983	2	13
May 19, 1983	2	9
Jun 2, 1983	9	16

TABLE 16. WATER BALANCES FOR SELECTED PERIODS

Plot	Year	Period	No. of Days*	Waste-Water Applied (cm)	Precipitation (cm)	Total Water Applied (cm)	Calculated ET (cm)	Measured Effluent (cm)	Infiltration** (cm)	Percent Water Recovery*** (%)
3	1982	Jun 22-Jun 29	6	42.0	2.7	44.7	3.4	17.9	23.4	40
3	1982	Sep 15-Sep 29	9	70.6	1.2	70.6	2.3	33.0	35.3	47
3	1982	Oct 8-Oct 18	5	38.9	1.1	40.0	2.6	16.4	21.0	41
3	1983	Jun 8-Jun 14	4	17.9	0.1	18.0	1.1	6.2	10.7	34
4	1982	Jun 16-Jul 2	12	55.6	1.3	56.9	6.1	27.8	23.0	49
4	1982	Aug 10-Aug 17	5	23.2	0.4	23.6	2.2	8.1	13.3	34
4	1982	Sep 20-Sep 24	5	24.7	0.1	24.8	1.5	7.8	15.5	31
4	1983	Jun 6-Jun 30	8	23.8	0.7	24.5	2.7	8.2	13.6	33
4	1983	Jul 1-Jul 26	13	62.9	3.0	65.9	6.8	23.3	35.8	35
6A	1983	Jun 6-Jun 30	9	26.3	0.7	27.0	2.9	14.0	10.1	52
6A	1983	Jul 1-Jul 26	13	40.3	3.0	43.3	6.8	11.6	24.9	27
6B	1983	Jun 6-Jul 14	5	15.1	0.6	15.7	1.3	6.2	8.2	39
6B	1983	Jul 1-Jul 8	4	13.5	0.6	14.1	2.2	5.9	6.0	42

*Water was not applied and/or measured every day during the period.

**Infiltration calcualted as the difference between Total Water Applied and the sum of ET plus effluent.

***Water recovery was calculated as the effluent divided by water applied, expressed as a percent.

TABLE 17. SUMMARY OF SURVIVAL OF PLANT SPECIES AT LARAMIE OVERLAND DISPOSAL SITE AFTER THE FIRST WINTER OF OPERATION

Plant Species	Transplanted Species Winter Survival (%)	Seeded Species Winter Survival (%)
Timothy	94	25
Redtop	43	2
Smooth bromegrass	100	50
Alsike clover	17	2
'Garrison' creeping meadow foxtail	97	100
Tall wheatgrass	83	5
Western wheatgrass	97	80
Reed canarygrass	100	40

had several inches of snow cover. In Laramie, even though winter temperatures are severe, snow accumulation is normally low. Thus, an insulating snow cover on the plots where treatment can occur does not develop.

Tables 8 through 12 show influent and effluent quality concentrations for monthly periods. The data clearly show the lack of treatment during the six winter months. Seasonal cycles are very apparent for NH_3-N, TKN, and BOD_5 concentrations in the wastewater effluent.

Effects of Loading Rates

Hydraulic loading rates from 10 to 30 cm/wk were used (Table 1). Comparing summer results for plot 5 with plot 3, both receiving primary wastewater and at rates of 10 cm/wk and 30 cm/wk respectively, shows that there was not significant difference at the 0.05 level in treatment between plots for BOD_5 and suspended solids (Table 13). However, plot 5 provided significantly better treatment for NH_3-N, total phosphates as PO_4, and TKN. In fact, plot 5 ranked last of all six plots in treating the latter three constituents.

On plots 1 and 2, which received raw wastewater and had loading rates of 15 cm/wk and 10 cm/wk, there were no significant differences in treatment for any of the five constituents listed in Tables 13 and 14.

Water Balance

Water balances were determined for selected time periods and not continuously throughout the duration of this project (Table 16). The water balances were determined by measuring the application rate and effluent flow rate from the plots and by calculating the evapotranspiration losses using the SCS Blaney-Criddle (SCS, 1967) formula as calibrated for the Laramie area for mountain meadow vegetation (Borrelli and Burman, 1982). Infiltration was then calculated as the difference between water applied and the sum of the effluent volume plus evapotranspiration.

Water balances were measured only for the plots with the higher application rates (20 and 30 cm/wk). Water balances were not obtained during the winter due to the impossibility of measuring runoff during winter and the difficulty of defining either evapotranspiration or infiltration.

The water recovery for the individual sampling periods ranged from 27% to 52% percent with an average recovery of 39% for the 13 sampling periods.

Plot 3 with an application rate of 30 cm/wk had a slightly higher average recovery rate (41%) than either plot 4 (37%) or plot 6 (40%) with application rates of 20 cm/wk. The wide range between the 27% and 52% recovery rates for plot 6A cannot be explained, except to note that the average of the two values is nearly identical to the overall average of 39% for all the 13 sampling periods.

Agronomic Results

One of the key factors for any successful overland flow system is a good stand of vegetation (most often some mixture of grass). As was the case in

Thayne, Wyoming (Borrelli et al., 1978), not all species of grass will survive winter irrigation and the added stress of a thick ice pack. Thus, an important design recommendation for any overland flow system is a recommendation of which grass to grow.

Table 17 shows winter survival of the eight seeded and transplanted species. During the first winter, the survival of the transplanted grasses was acceptable, with the exception of redtop. The legume alsike clover did not adapt to winter flooding even though the species is rather tolerant to summer flooding in normal agricultural hay production. The survival of the seeded species was excellent for 'Garrison' creeping meadow foxtail and acceptable for western wheatgrass. By the end of the second growing season, reed canarygrass had also developed into an acceptable stand due to rhizomic activity. The other five species apparently did not obtain adequate growth during the seeding year to survive the winter flooding. The adaptation of 'Garrison' creeping meadow foxtail to winter water treatment was previously reported by Greene et al. (1980). The survival of the transplanted sod was excellent during the first year.

During the second year of operation, a dramatic change in vegetation composition occurred. The 'Garrison' creeping meadow foxtail dominated at the end of the second winter (the beginning of the third growing season) on both the seeded and sodded plots. Apparently, the sedges and rushes originally in the sodded plots were not able to compete well with the 'Garrison' creeping meadow foxtail. On the other hand, the 'Garrison' creeping meadow foxtail continued to dominate on the seeded plots, as it had in previous years, except that its dominance became more prominent.

The sodded plots, in general, were superior in treatment of the primary water until the middle of the summer of 1982. At this time the vegetation on the seeded plots developed a crop canopy that nearly completely covered the soil. During the first year there was considerable erosion from the seeded plots.

During the first year of operation, the ice packs which formed on the plots during winter started to form nearly two weeks earlier on the seeded plots than on the sodded plots (Figure 6). The denser vegetation on the sodded plots as compared to the seeded plots apparently acted as an insulating layer keeping the soil, and therefore the wastewater, warmer than on the seeded plots. At their maximum development, the ice packs on the sodded plots covered about the lower third of the raw plots and the lower half of the primary plots. The seeded plots were at times completely covered by ice packs, although the depth of the ice was very thin at the influent end.

Yields were taken from two cuttings during 1983. The cutting dates were June 23rd and August 26th. Samples were cut from both the top and bottom of the plots. In all cases total yield was greater on the top half of the plot than the bottom half with the difference being 2.8 t/ha. Seasonal yields up to August 26th are shown in Table 18.

TABLE 18. FORAGE YIELDS FROM TEST PLOTS FOR 1983

Plot No.	Seasonal Yield (ha)
1	8.69
2	10.97
3	8.27
6A	7.56
4	8.58
5	9.74
6B	10.20

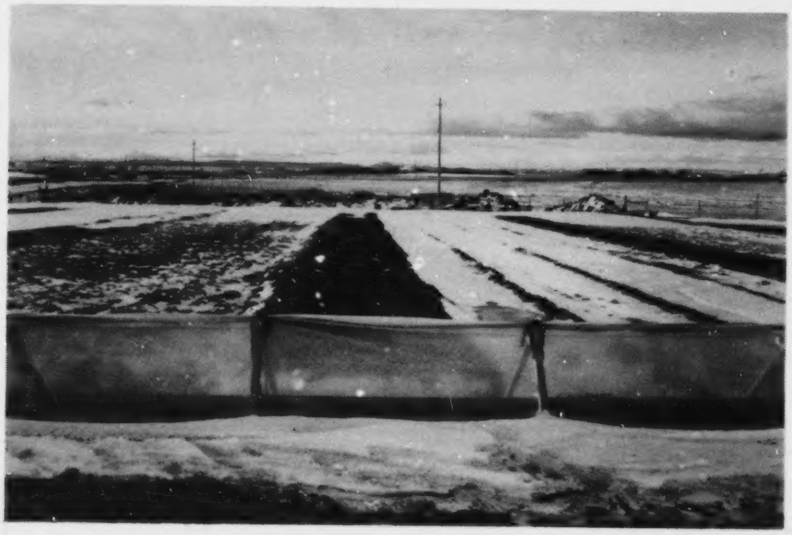

Figure 6. Ice buildup on sodded plot (left) vs seeded plot (right)

SUMMARY

The results of this project show that a wastewater distribution system for overland flow treatment can be made to operate in a severe northern climate such as exists at Laramie. The distribution system applied wastewater virtually without any problems for two years except for plugging of the gated pipe used for delivery of wastewater on the raw plots.

Vegetation, mainly 'Garrison' creeping meadow foxtail, survived when planted from seed and was nearly fully established during the second growing season. However, wastewater treatment on the seeded plot was significantly lower than on the sodded plots, indicating time on the order of one to two years is required for establishing vegetation.

The system was marginal in achieving treatment to meet the minimum required discharge standards for secondary treatment. Treatment was adequate only during the warmer months of May through October and mainly on plots receiving raw wastewater. Treatment during the colder months was very poor.

Much of the reason for the lack of treatment during the winter months at Laramie appears to be due to the low amounts of snowfall received. The plots were generally bare except for the ice packs which developed on the lower portions of the plots due to the freezing of the wastewater. The lack of treatment during the winter would necessitate storage for winter flows as well as a provision for pumping back effluent from the treatment system during the spring when the bacterial community is being established on the plots.

One problem with storage is the cooling of the wastewater which occurs. The warmer raw wastewater was treated more completely by the overland plots in early spring than the cooler primary plots.

QUALITY ASSURANCE

The Wyoming Department of Agriculture, Division of Laboratories, analyzed all water quality samples. The laboratory used methods and procedures in accordance with those specified by EPA-600/4-79-019 and EPA-600/4-79-020. Quality control of results were monitored by using reference samples sent to the laboratory and by testing duplicate samples.

Reference samples were periodically sent to the laboratory by this project and other organizations. Presented in Appendix F are the results for reference samples processed during the period covered by this project. The only tests having reported values differing by more than two-standard deviations are those with very small concentrations. This occurred in one of 11 samples for total phosphate, one of 15 samples for NO_3-N, and one of seven samples for NH_3-N.

Approximately 30% of all samples tested were duplicates. The results of these samples are reported in Appendix A. Duplicate samples can be found in Tables 19 through 30 by observing Column One of each table. Those samples within any table having the same date of collection are duplicates. It is assumed that any differences in results are caused by the analyses performed by the laboratory. This assumption, however, may not be totally valid for any parameter that could be affected by algae counts and/or floating organic matter.

The duplicate samples wastewater parameters were tested statistically for % error of measurement using the T-test statistic. Error was defined as

$$\% \text{ Error} = \frac{\text{Sample 1} - \text{Sample 2}}{(\text{Sample 1} + \text{Sample 2})/2}(100) \qquad (1)$$

The sample sets for each wastewater parameter were tested for 10% or less average error and 15% or less average error using a 95% confidence interval. The % average error was 10% or less for specific conductance, TKN, O-P, and T-P. All the parameters had 15% or less average error at the 95% confidence interval.

SECTION 6

SURGE FLOW

INTRODUCTION

A variety of wastewater distribution systems have been used to apply wastewater to the top of overland flow plots. These methods include spray irrigation, using an assortment of nozzles, and surface irrigation methods ranging from flood irrigation to troughs with trickling orifices. Most of these wastewater distribution methods require at least primary wastewater treatment, with many using secondary effluent from existing wastewater treatment facilities (Foug, 1981; Carlson, 1974; Reynolds, 1980; Tucker, 1980; Leland, 1975; and Haigh, 1977). One purpose of using the pretreated wastewater is to eliminate the suspended solids which otherwise tend to plug the overland flow distribution system. Overland flow has been shown, though, to effectively treat raw sewage water without pretreatment (Martell, 1980). However, the low loading rates required for good water treatment on an overland flow plot dictate that some form of screening be done to eliminate large particles which can cause plugging problems in the hydraulic application system.

The extremely low flow rates required on the overland flow wastewater plots for this project meant that the sliding gates on the pipe would only be opened slightly (<1.0 cm). The solid particles in the raw wastewater line for plots 1 and 2 often quickly plugged the opening on the sliding gates. This, to a great extent, changed the flow rate to the raw wastewater plots. The influent to the primary wastewater plots did not encounter the same problem. The sliding gates could be left for several days (or weeks) before a small scum formed, and the opening had to be cleaned. The plugging problem described here caused the treatment system to be labor intensive. To solve the plugging problem, the sliding gate opening size had to be increased to allow the solids to pass. This would increase flow rates above desired loading rates. One way to increase the flow rate and still apply the same amount of water was to pulsate the flow. The question then became one of how the water would travel in a series of surges down the plot, and whether this would still suitably treat the water. Would the grass surface damp out the series of surge waves to a continuous flow runoff pattern at some distance down the plot length? If the surge flow action could be damped out to simulate continuous flow, then the rest of the plot should see little change, and treatment of approximately the same quality would be retained on the lower sections of the plots. This method of applying water in an intermittent or pulsating fashion according to a specified cycle of on and off times is called surge flow. In an attempt to answer these questions, surge flow tests were conducted on a model in the laboratory and on one of the two raw wastewater plots in the field.

MODEL TESTING

The model design was based upon a Froude number approach, assuming that the artificial turf selected would correctly simulate the viscous forces in the actual plot. The laboratory model has a 7:1 length scale ratio, and the artificial turf was installed in 1.2 m sections down the model to give a total of five test length sections (total length of 6.1 m in the model, or 42.7 m in the field). A series of tests were conducted at each of the sections before another section was added and the tests repeated. This was done in an effort to see how damping of the surges was occurring with plot length.

A constant head reservoir designed with a butterfly valve and simulated gated pipe section (five different sections were built for flow rate variability) was used to produce the correct model flow rates for surge flow application. Bishop (1980) performed surge flow irrigation and found that a time cycle ratio of 2/3 on time to 1/3 off time simulated continuous flow after a short distance down an irrigated furrow. A number of time cycle ratios in a range around 2/3 on to 1/3 off were thus tested along with duration of the cycle times (2 min:1 min and 10 min:5 min).

An adjustment was made to the continuous flow rate values for a given time cycle ratio to produce the same volume of flow onto the plots as with a continuous flow. A collection channel and orifice meter were used to measure runoff at the bottom of the test sections.

The testing of the model consisted of surging the influent flow with the use of the butterfly valve at a particular time cycle ratio and duration while simultaneously recording the runoff at the bottom of the test section. Details of the control, measurement, and operation procedures of the tests are in Appendix C.

The model test data of instantaneous runoff versus time were plotted to give hydrographs as shown in Figure 7. These hydrographs show the peak and valley flow pattern that is expected with surge flow application. The variable of most interest in the search for a cycle time, loading rate, and damping length that will match a continuous runoff pattern is the average range value between the peaks and valleys of the hydrograph. This average range value was determined by taking the average peak value and subtracting the average valley value of the cyclic data. Average range value will carry the same meaning throughout this paper. An average range value of zero would indicate that the test parameters of cycle time, loading rate, and damping length were combined in the correct fashion to simulate a continuous flow pattern. Even though all three of the model parameters were interrelated in the production of the average range value, an attempt was made to define the relationship between the average range and each parameter individually. Details of the individual analyses are contained in Appendix C.

The results of the analysis on the model test data indicated:

1. The cycle ratio of 2/3 on to 1/3 off appears to lead to a runoff flow pattern that is the closest to a continuous flow pattern, when compared to cycle ratios of shorter on time.

2. Average range is a function of damping length, loading rate and cycle time. The parameter characteristics:

   a. Increased damping lengths decrease the average range in the runoff hydrograph.

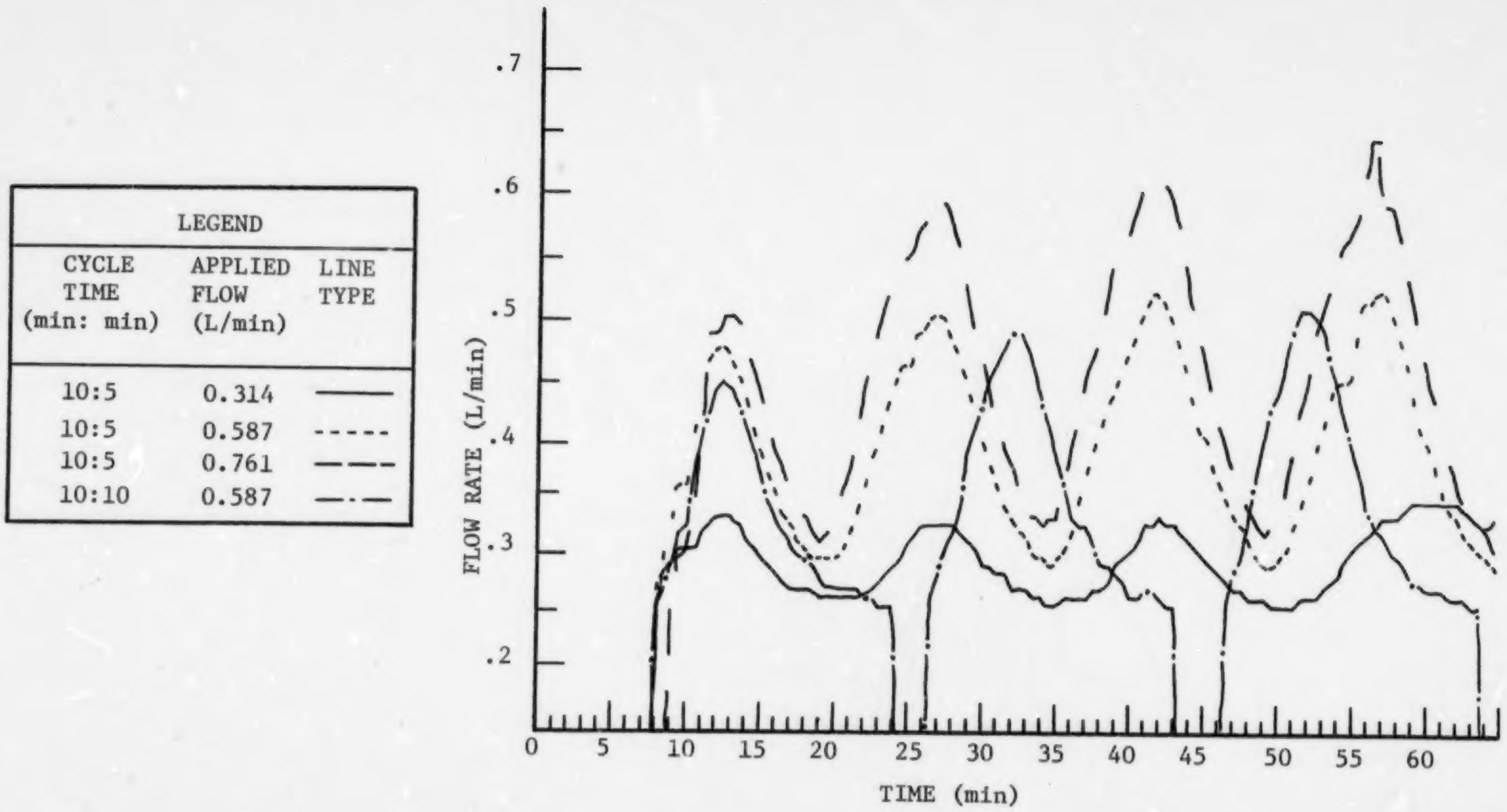

Figure 7. Model runoff hydrograph (4.9 m).

b. Decreased loading rates decrease the average range in the runoff hydrograph.

c. Shorter cycle times create smaller average range values in the runoff hydrograph.

This information was used in the field tests.

FIELD TESTS

Surge flow testing was performed on the most westerly of the two raw wastewater overland flow plots (Plot 1). The influent flow was applied through one gate in the gated pipe. To surge the flow applied to the plot influent, the sliding gate was opened and closed manually in conjunction with the appropriate cycle times.

The overland flow plot was divided into five sections corresponding to the same section lengths used in the model study (8.5 m sections). A small channel was cut across the plot to collect the runoff at the bottom of each of the test sections. A section of 15.24 cm pipe was split in half and installed to extend the channel to a trapezoidal 60 degree flume. Mounted on the flume was a continuous recorder which measured flow rate. Details of the testing procedure are in Appendix C.

The instantaneous runoff flow rate data which were recorded in the field were plotted against time to give runoff hydrographs. Figure 8 shows these. Again, as in the model, these hydrographs were studied to determine the relationship between the average range value and damping length, flow rate, and cycle time. To keep the prototype analysis parallel to the model study, these parameters were examined in the same fashion as the model data. Details of these analyses are in Appendix C.

The results of the analysis on the field data indicate that:

1. As the field length increased, the average range value was reduced for given flow rates and cycle times. The results also indicated that water applied in a surge flow pattern is damped out to a continuous flow pattern at some distance down the plot.

2. The time cycle ratio of 2/3 on to 1/3 off resulted in a runoff flow pattern with the smallest average range for time cycle ratios of shorter on times.

3. Average range is a function of damping length, loading rate, and cycle time. The trend of the relationship between these three parameters and the average range is:

   a. Longer damping length results in a runoff flow pattern of a smaller average range value.

   b. Shorter cycle times reduce the average range values.

   c. Smaller loading rates lead to less intense average range values.

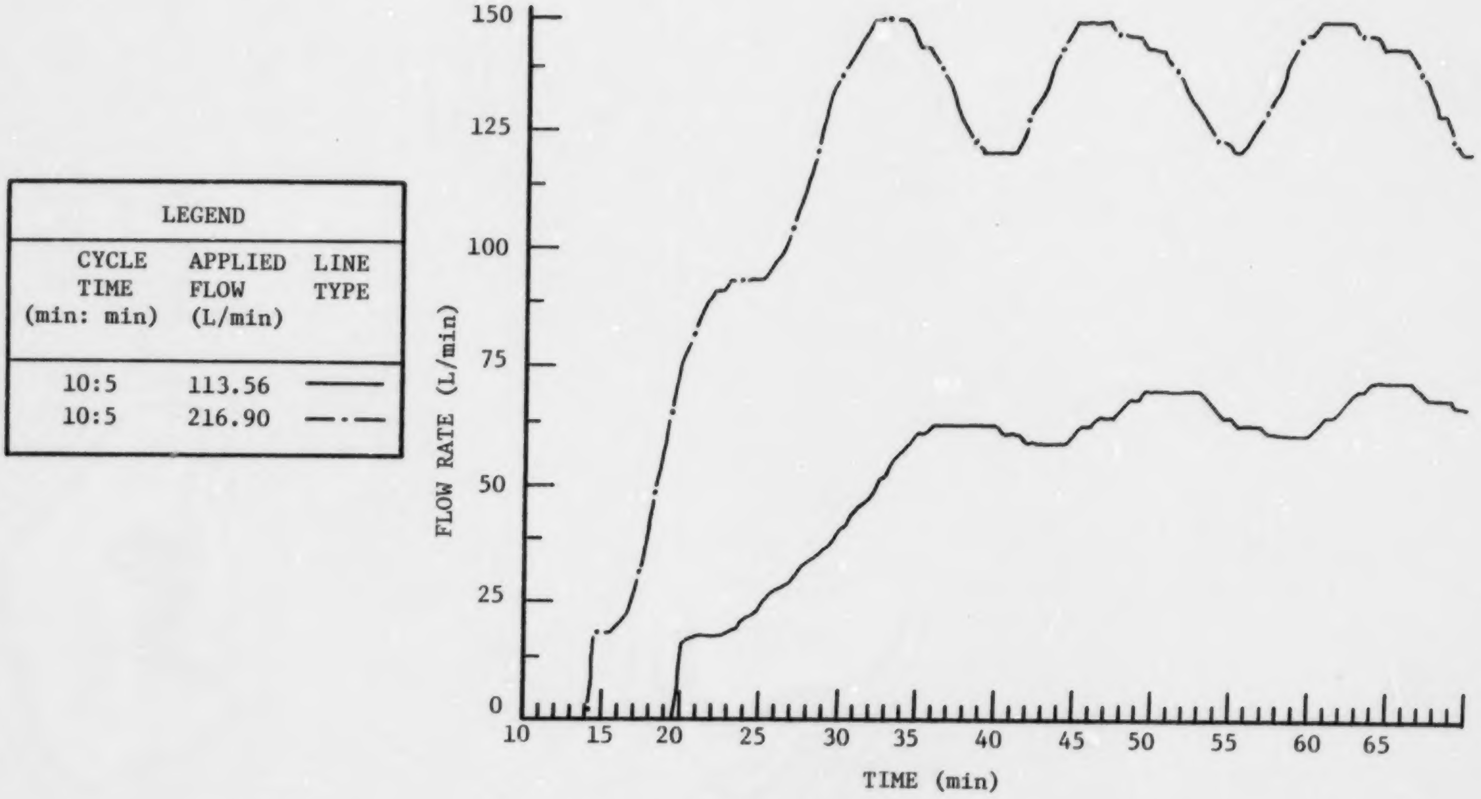

Figure 8. Prototype runoff hydrograph (25.6 m).

RESULTS

The average range values for the model were much more severe than in the field situation. A comparison of Figures 7 and 8 for flow rates of 0.76 L/min (model flow rate approximately same as field flow rate of 113.6 L/min) and 113.6 L/min, respectively, indicates this. The timing was also somewhat different except that the time length of cycles was approximately the same. These discrepancies were most likely a result of 1) the artificial turf not representing the actual grass very well in term of viscous shear, 2) infiltration losses existing in the field situation but not in the model, and 3) the model not adequately simulating the ground surface roughness. Because of these inconsistencies, the model data were not directly compared with the field data. However, the analysis of both sets of data indicated that the surge flow runoff pattern initiated by the intermittent water application at the influent can be damped to simulate a continuous flow runoff pattern by:

1. Lengthening the damping section of the overland flow plot.
2. Decreasing the loading rate applied at the influent.
3. Using exclusively time cycle ratios which contain longer on times in conjunction with shorter off time periods such as the 2/3 on to 1/3 off cycle ratio.
4. Shortening the on and off cycle times periods.

Some major problems exist with altering just one of these parameters. For example, when the damping section of the plot is lengthened, an increase in wetted surface area will cause a rise in evapotranspiration and infiltration losses, not to mention the increase in overall size of the overland flow plots resulting in higher construction costs. Because of these inherent problems, the damping length should be selected with the shortest length possible in mind.

Caution should also be taken when adjusting the loading rate. The loading rate is usually specified at levels that are conducive to quality water treatment. Tampering with this value may lead to problems in treatment quality. When surge flow is used in the overland flow treatment system, the slide gate opening at the influent should be computed first. The experience of running the overland flow prototype shows that a gate opening of less than 1.0 cm could be expected to cause a plugging problem, especially when raw wastewater is applied. The exact slide gate opening size through which solids of the raw or primary wastewater will pass without plugging was not determined. If this value could be found, it could be used as a minimum size for which continuous flow application is practical. Loading through more than one slide gate, using surge flow methods, could be considered for slide gate openings at or above this determined minimum size.

The most flexible parameter in an overland surge flow treatment system is the cycle time. About the only bounds to its selection is the ability of the mechanical devices used to surge the flow. Research has shown that a continuous runoff flow pattern can be mimicked best by using the shorter on and off times; thus an impossible work load could be placed on the equipment.

In spite of this limitation, the choice of a cycle time is probably the most flexible in obtaining the desired runoff pattern.

Figure 3 was developed from field data analysis to help in the simultaneous selection of loading rate, damping length, and cycle time. This graph has lines of zero average range drawn for specific cycle times between loading rate and damping length. Since the design of an overland flow treatment system usually requires a certain loading rate to provide good water treatment, this is usually a known value. Using this set value, a cycle time can be chosen to give an average range value of zero at a desired damping length. If any one of the three parameters is known, the same can be done to obtain the other two. Some freedom can be used in these selections if the zero average range value is not required and a small amount of average range can be tolerated.

It should be emphasized that the graph in Figure 9 is by no means complete. Only a limited amount of data were available at the time of construction. It should be used only as a guideline to the selection of cycle time for an overland flow plot which has similar slope and surface roughness to this field test.

CONCLUSIONS

Surge flow shows promise as a solution to plugging problems of an overland flow treatment system in which gated pipe is used. The results of the analysis of the data from both the model and field study indicated that (1) a cycle ratio of 2/3 on to 1/3 off will simulate a continuous flow pattern in the shortest damping length, and (2) damping to a continuous flow pattern can be attained by extending the field damping length, decreasing the loading rate, or by using shorter cycle times. Figure 9 can be used as a guide for this.

The major benefits of using surge flow are:

1. It will help solve the influent plugging problem which occurs at the lower application rates necessary for good water treatment.
2. It will give the overland flow water treatment system a measure of automation by providing it with a dependable water delivery system.

LEGEND							
CYCLE TIME (min:min)	LOADING RATE (Lph)	PROTOTYPE LENGTH (m)	POINT DESCRIPTION	CYCLE TIME (min:min)	LOADING RATE (Lph)	PROTOTYPE LENGTH (m)	POINT DESCRIPTION
2:1	1726	8.5	○	10:10	1294	17.1	□
	4542	8.5	⬡		3407	42.7	△
10:5	1726	17.1	⊙		6506	51.2	◁
	4542	34.1	◇	10:20	2271	42.7	▷
	8675	51.2	▽		4338	51.2	⏣

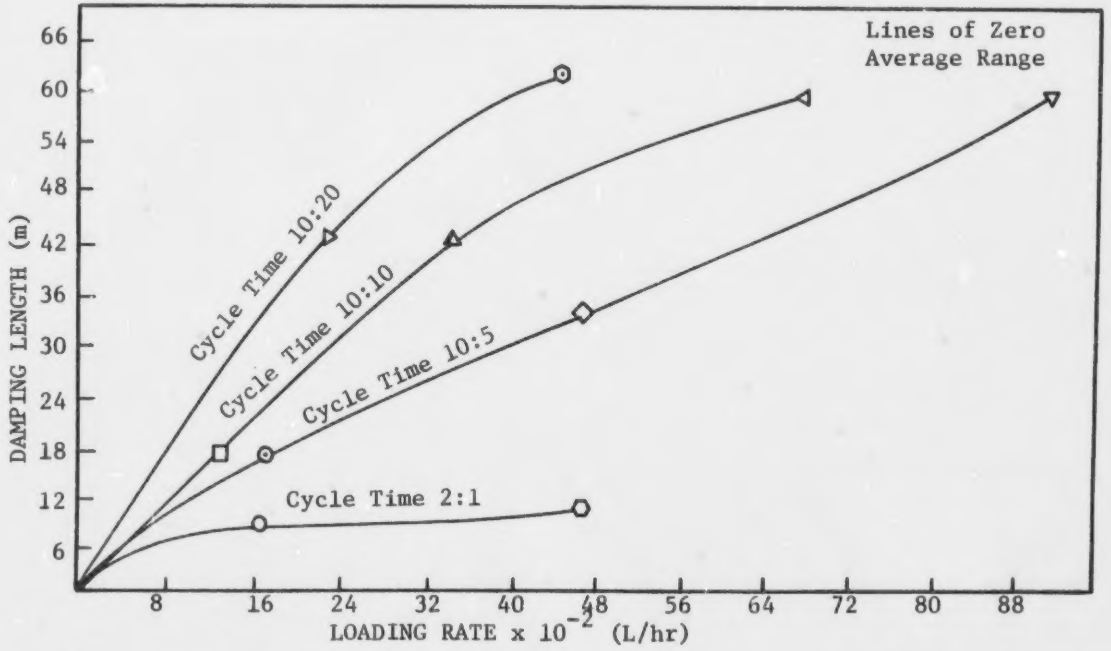

Figure 9. Prototype data: graph for parameter selection at zero average range values.

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APPENDIX A

WATER CHARACTERISTICS

TABLE 19. RAW WASTEWATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810730	13.0	14.	1900	.05	7.6	16.0	17.0	0	0	18.	-99.00	66	146000	-99.0	-99.00	-99.0
810806	18.0	14.	1860	.07	7.5	18.0	19.0	16	16	22.	-99.00	61	71000	19.0	.02	-99.0
810903	35.0	33.	1510	.03	7.3	16.0	18.0	38	30	40.	31.94	118	4000000	18.0	1.40	7.5
810917	21.0	28.	1590	.08	7.4	11.0	12.0	16	16	31.	34.28	79	60000000	18.0	1.40	7.4
810917	39.0	38.	1600	.08	7.4	12.0	12.0	16	16	49.	29.55	70	30000000	18.0	1.40	7.4
811006	20.0	89.	1440	.04	7.4	24.0	26.0	68	56	37.	80.81	140	90000000	19.0	1.80	7.4
811022	20.0	140.	1440	0	7.6	13.0	19.0	44	44	25.	83.01	120	300000000	15.0	2.60	7.2
811022	18.0	120.	1420	0	7.7	14.0	18.0	68	66	33.	60.18	120	300000000	16.0	2.80	6.6
811105	27.0	100.	1290	1.53	8.0	13.0	16.0	56	46	38.	50.42	126	4000000	15.0	3.20	7.5
811105	35.0	100.	1330	.15	8.0	14.0	20.0	34	30	37.	56.18	127	1500000	15.0	3.30	7.6
811119	22.0	130.	1350	.05	7.8	17.0	24.0	78	66	35.	65.26	140	1500000	12.0	2.60	7.2
811203	25.0	63.	1330	.05	8.2	15.0	15.0	50	18	35.	73.44	130	3000000	12.0	2.40	7.9
811203	26.0	65.	1320	.03	8.2	14.0	15.0	46	16	34.	87.08	140	3000000	12.0	2.20	7.8
811217	22.0	14.	1510	.08	7.6	13.0	20.0	110	70	38.	-99.00	120	2000000	11.5	2.30	7.3
811230	21.0	100.	1850	0	8.1	11.0	16.0	46	32	30.	61.47	120	2000000	11.0	3.00	7.9
811230	21.0	100.	1840	0	8.1	9.5	12.0	52	36	30.	68.74	110	3100000	11.0	3.50	7.9
820114	22.0	220.	1330	2.20	7.5	20.0	24.0	140	100	37.	78.70	130	4400000	12.0	-99.00	8.7
820128	24.0	180.	1370	0	7.9	14.0	17.0	96	76	36.	56.19	160	3200000	11.0	1.80	7.8
820128	23.0	150.	1350	0	7.9	15.0	17.0	110	84	37.	71.34	150	3200000	11.0	1.80	7.7
820211	23.0	140.	1290	0	8.1	15.0	17.0	92	72	35.	60.97	150	2200000	10.0	2.20	-99.0
820225	22.0	90.	1280	0	8.0	16.0	17.0	86	80	34.	23.02	150	3600000	11.0	1.20	-99.0
820225	22.0	95.	1270	0	8.0	17.0	18.0	76	74	34.	22.58	130	4600000	11.0	1.20	-99.0
820311	19.0	83.	1580	.40	7.8	11.0	21.0	40	36	30.	47.59	100	3500000	11.0	2.40	-99.0
820506	23.0	160.	1480	.10	7.8	15.0	21.0	86	22	32.	66.10	190	3900000	14.0	2.40	7.5
820506	22.0	150.	1460	.10	7.8	14.0	21.0	90	18	32.	71.38	190	3200000	13.0	2.60	7.7
820520	21.0	100.	1960	.10	7.5	13.0	18.0	74	26	29.	31.26	81	5400000	12.0	.80	7.7
820603	17.0	120.	1770	.10	7.7	16.0	23.0	106	84	27.	46.49	170	5600000	13.0	.40	7.5
820603	18.0	120.	1760	.10	7.7	16.0	25.0	102	80	27.	46.00	170	3300000	13.0	.30	7.6
820617	20.0	110.	1590	0	7.2	14.0	18.0	52	44	27.	63.75	130	3700000	16.0	-99.00	7.3
820701	19.0	140.	1720	0	7.3	15.0	19.0	76	58	29.	83.80	210	3200000	18.0	.40	7.3
820701	17.0	55.	1710	0	7.3	13.0	19.0	58	42	28.	83.90	210	9000000	18.0	.40	7.4
820715	24.0	240.	1820	0	7.3	14.0	21.0	70	58	32.	88.50	260	100000	19.0	.70	7.2
820805	20.0	150.	1830	0	7.4	14.0	16.0	70	54	25.	32.36	98	2280000	20.0	.10	7.7
820805	21.0	140.	1830	0	7.6	14.0	16.0	58	42	25.	33.67	92	2000000	20.0	.20	7.7
820902	29.0	83.	1380	0	7.4	16.0	17.0	54	40	34.	23.39	120	4200000	21.5	.20	7.4
820916	26.0	160.	1480	40.00	7.7	15.0	19.0	64	50	31.	28.00	140	4100000	19.0	.70	7.0
820916	27.0	290.	1510	32.00	7.7	14.0	30.0	62	46	31.	24.00	150	4300000	19.0	.50	7.3
820930	25.0	200.	1670	0	7.7	11.0	16.0	54	42	29.	22.00	99	30000000	14.0	.58	6.7
821014	27.0	220.	1470	27.00	7.7	18.0	19.0	26	26	32.	31.20	170	3200000	15.0	2.50	6.9
821014	28.0	210.	1530	16.00	7.7	19.0	19.0	56	54	32.	26.40	160	2700000	15.0	2.00	7.2
821028	27.0	290.	1610	.10	7.5	19.0	19.0	36	28	32.	38.70	120	3000000	13.0	.50	7.1
821110	30.0	61.	1190	30.00	7.8	15.0	22.0	14	14	35.	18.58	150	3000000	14.0	1.20	-99.0
821110	28.0	57.	1230	43.00	7.8	13.0	19.0	14	14	34.	27.07	140	3600000	14.0	1.20	-99.0
821118	26.0	43.	1560	0	7.6	15.0	16.0	30	22	32.	21.18	150	2500000	13.0	2.00	6.8
821202	24.0	460.	1450	4.00	7.7	16.0	20.0	16	10	34.	42.43	130	100000000	11.0	1.50	7.4
821202	24.0	350.	1490	0	7.7	16.0	26.0	36	26	34.	42.91	140	2800000	11.0	1.80	7.0
821216	23.0	130.	1350	0	7.3	13.0	21.0	88	64	36.	72.49	130	2600000	11.0	1.30	7.1
821230	20.0	150.	1580	0	7.7	17.0	20.0	34	22	29.	34.29	150	100000	10.0	1.40	6.8
821230	21.0	190.	1580	0	7.7	17.0	20.0	32	18	29.	39.67	150	1700000	10.0	1.00	6.7
830113	27.0	340.	1280	0	7.5	17.0	19.0	120	110	42.	141.90	330	1800000	10.0	2.80	6.8
830127	21.0	87.	1360	34.00	7.7	16.0	17.0	10	0	29.	21.07	130	1400000	12.0	3.40	6.4
830127	23.0	130.	1350	37.00	7.7	20.0	20.0	22	14	29.	19.48	100	1900000	11.0	2.40	6.2
830210	33.0	170.	1220	0	7.5	16.0	16.0	42	30	34.	26.48	190	2800000	10.0	2.60	6.9
830224	32.0	220.	1260	.10	7.8	12.0	17.0	64	130	34.	68.84	220	3800000	11.0	2.70	7.0
830224	32.0	280.	1270	.10	7.9	13.0	18.0	64	48	33.	73.88	240	3100000	11.0	2.30	6.7
830310	14.0	220.	1620	.10	7.5	9.9	13.0	64	50	26.	52.06	120	2600000	11.0	2.00	6.9
830324	22.0	250.	1540	0	7.7	11.0	17.0	52	48	30.	66.51	140	2800000	10.0	2.80	7.6
830324	23.0	250.	1560	0	7.8	12.0	23.0	40	40	31.	68.29	140	2700000	10.0	2.60	7.4
830407	24.0	260.	1560	0	7.5	11.0	18.0	62	54	30.	90.43	135	2200000	11.0	-99.00	8.2
830421	18.0	130.	1900	0	7.5	7.5	9.5	38	32	25.	43.30	110	1800000	9.0	4.00	8.3
830421	18.0	140.	1920	0	7.5	8.7	12.0	34	30	25.	43.22	98	2500000	9.0	3.40	8.1
830505	17.0	120.	1920	0	7.5	9.3	9.8	28	20	24.	46.91	81	2400000	12.0	3.70	7.5
830519	14.0	120.	2350	0	7.5	10.0	12.0	24	16	21.	55.73	130	1800000	10.0	3.70	7.6
830519	14.0	140.	2350	0	7.6	11.0	11.0	26	20	20.	59.41	130	1400000	10.0	3.80	7.8
830602	12.0	200.	2210	0	7.5	8.9	9.6	0	0	21.	30.64	83	1300000	14.0	3.00	6.9
830616	15.0	170.	2090	.10	7.3	12.0	14.0	24	22	20.	57.06	110	3100000	15.0	1.40	7.1
830616	14.0	230.	1930	.10	7.3	12.0	12.0	26	24	20.	58.77	110	3000000	15.0	1.50	7.0
830630	16.0	170.	2060	.10	7.3	12.0	12.0	22	22	23.	61.06	93	2900000	17.0	1.40	7.7
830714	16.0	120.	1970	0	7.2	12.0	12.0	44	22	25.	48.02	110	7500000	20.0	1.20	7.9
830714	15.0	110.	1990	0	7.3	12.0	12.0	38	20	24.	37.16	97	3000000	19.0	.80	7.9
830728	13.0	130.	1910	0	7.4	12.0	13.0	52	44	25.	29.82	100	5200000	20.0	2.70	7.4

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TABLE 20. PRIMARY WASTEWATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810806	15.0	15.	1880	.24	8.1	18.0	18.0	16	16	18.	-99.00	49	7000	19.0	.60	-99.0
810821	4.6	37.	1830	.08	7.3	13.0	15.0	16	16	29.	33.32	72	700000	17.0	.60	7.3
810903	15.0	47.	1700	.03	7.6	14.0	15.0	14	14	20.	34.00	68	4000000	16.0	1.20	7.4
810917	20.0	55.	1520	7.50	15.0	16.0	32.0	32	35	40.	75.00	80	50000000	19.0	.20	7.4
811006	26.0	97.	1420	.01	7.3	18.0	21.0	16	16	27.	42.98	100	40000000	15.0	2.00	7.0
811006	20.0	120.	1540	.02	7.3	19.0	22.0	20	20	33.	67.32	99	30000000	15.0	1.80	7.1
811022	23.0	140.	1520	0	7.8	16.0	20.0	18	18	31.	59.34	82	29000000	9.0	1.40	7.4
811105	19.0	84.	1550	.07	7.8	16.0	18.0	12	12	26.	43.16	84	560000	7.0	1.20	7.4
811119	18.0	93.	1570	.07	7.8	16.0	19.0	20	20	28.	44.04	79	440000	4.0	1.10	7.3
811119	20.0	110.	1560	.08	7.8	16.0	18.0	18	18	29.	41.79	86	510000	4.0	.90	7.4
811203	23.0	75.	1580	.03	7.8	17.0	22.0	8	4	29.	66.45	96	730000	3.0	2.20	7.4
811217	21.0	96.	1550	.07	7.6	17.0	18.0	26	22	27.	-99.00	120	930000	3.5	2.40	7.2
811217	21.0	98.	1540	.06	7.7	17.0	20.0	30	24	29.	-99.00	120	580000	3.5	3.20	7.2
811230	21.0	84.	1320	0	7.5	16.0	16.0	22	16	27.	35.04	130	1400000	5.0	4.00	7.0
820114	23.0	150.	1510	0	7.5	16.0	17.0	48	34	29.	38.78	110	1800000	5.5	-99.00	7.2
820114	22.0	160.	1540	0	7.6	15.0	16.0	48	36	28.	36.92	120	1900000	5.5	-99.00	7.2
820128	22.0	170.	1460	0	7.6	16.0	17.0	24	22	29.	53.68	120	1600000	5.0	2.60	7.6
820211	23.0	160.	1510	0	7.6	17.0	20.0	22	18	33.	42.60	140	1300000	4.0	2.40	-99.0
820211	23.0	160.	1510	0	7.5	17.0	18.0	36	28	33.	28.88	140	800000	4.0	2.50	-99.0
820225	21.0	150.	1330	0	7.6	15.0	16.0	16	16	27.	23.28	110	620000	5.0	3.60	-99.0
820311	21.0	130.	1420	0	8.0	16.0	19.0	28	28	27.	44.11	110	7300000	6.0	2.50	-99.0
820311	22.0	110.	1410	0	7.7	15.0	19.0	24	24	27.	43.09	110	510000	6.0	2.40	-99.0
820506	28.0	150.	1540	.10	7.6	17.0	21.0	22	6	28.	55.67	88	700000	10.0	2.00	7.6
820520	20.0	130.	1670	.10	7.6	17.0	22.0	8	8	25.	44.81	63	390000	11.0	1.40	7.7
820520	20.0	120.	1600	.10	7.5	17.0	20.0	16	16	27.	41.10	78	1100000	11.0	1.80	7.8
820603	17.0	99.	1700	.10	7.8	16.0	21.0	44	42	25.	39.07	889	530000	12.5	2.20	7.7
820617	15.0	80.	1770	0	7.6	15.0	18.0	22	22	20.	45.77	71	200000	15.0	-99.00	7.6
820617	15.0	68.	1780	0	7.5	15.0	16.0	28	28	20.	55.37	66	500000	15.0	-99.00	7.7
820701	11.0	67.	1800	0	7.8	15.0	17.0	26	18	21.	33.00	58	100000	19.0	.40	7.7
820715	15.0	84.	1810	0	7.7	14.0	18.0	30	26	20.	29.00	89	50000	21.0	.20	7.4
820715	15.0	84.	1800	0	7.7	14.0	17.0	26	22	20.	28.75	53	10000	20.0	.20	7.3
820805	11.0	120.	1820	0	7.8	14.0	15.0	56	48	19.	35.27	47	2500000	21.0	.20	7.6
820902	13.0	100.	1720	0	7.8	16.0	16.0	34	28	19.	35.45	100	300000	20.5	.20	7.4
820902	12.0	110.	1720	0	7.7	15.0	16.0	46	40	19.	33.37	85	700000	17.0	.90	7.4
820916	19.0	170.	1560	14.00	8.0	14.0	16.0	12	12	22.	29.00	66	100000	15.0	.40	7.5
820930	20.0	82.	1640	0	7.8	12.0	16.0	36	30	23.	18.00	75	7400000	10.0	.60	6.8
820930	20.0	100.	1640	0	7.8	12.0	15.0	40	38	23.	17.00	70	1190000	10.0	.60	7.0
821014	20.0	120.	1480	20.00	7.8	18.0	19.0	26	24	24.	21.80	73	300000	9.0	2.90	7.2
821028	18.0	170.	1540	12.00	7.7	18.0	18.0	38	30	23.	24.20	57	600000	6.0	.70	7.2
821028	19.0	130.	1530	15.00	7.7	18.0	18.0	26	26	23.	23.80	66	900000	6.0	.70	7.2
821110	21.0	38.	1590	12.00	7.7	15.0	26.0	8	8	24.	19.54	91	500000	7.0	1.20	-99.0
821118	22.0	120.	1630	16.00	7.8	14.0	14.0	12	10	26.	20.63	92	500000	6.0	1.60	6.8
821118	22.0	110.	1600	27.00	7.7	13.0	14.0	10	8	26.	21.32	92	400000	6.0	1.40	6.8
821202	19.0	120.	1620	0	7.5	14.0	17.0	12	10	25.	38.81	100	500000	3.0	4.60	7.2
821216	21.0	160.	1620	0	7.3	14.0	23.0	14	14	28.	32.66	100	200000	6.0	2.20	7.4
821216	22.0	170.	1600	0	7.4	14.0	19.0	12	10	27.	30.76	110	700000	5.0	2.50	7.1
821230	23.0	84.	1630	0	7.3	16.0	22.0	8	0	27.	43.49	120	800000	4.0	1.40	6.6
830113	23.0	120.	1560	0	7.3	17.0	19.0	34	32	27.	47.43	96	400000	5.0	3.60	7.1
830113	23.0	120.	1570	0	7.4	16.0	19.0	30	22	27.	46.37	100	400000	5.0	3.40	7.0
830127	26.0	110.	1430	11.00	7.3	14.0	16.0	0	0	26.	40.43	140	200000	8.5	2.60	6.2
830210	25.0	150.	1470	0	7.1	16.0	16.0	10	8	27.	44.25	170	600000	3.5	2.40	6.6
830210	25.0	150.	1470	0	7.3	15.0	15.0	10	10	27.	44.60	160	1200000	3.0	2.60	6.6
830224	24.0	140.	1300	.10	7.4	15.0	15.0	12	10	24.	34.03	130	500000	7.5	1.80	6.6
830310	17.0	210.	1310	.10	7.6	13.0	14.0	18	18	22.	41.61	98	100000	10.0	1.00	6.9
830310	17.0	120.	1300	.10	7.6	12.0	13.0	18	18	23.	42.00	84	100000	9.0	1.20	6.8
830324	21.0	110.	1510	0	7.7	12.0	19.0	14	14	24.	39.65	100	500000	6.0	1.90	7.3
830407	22.0	130.	1630	0	7.6	9.8	19.0	30	28	24.	31.87	100	100000	6.0	-99.00	8.1
830407	22.0	100.	1630	0	7.6	10.0	19.0	42	28	24.	29.92	92	500000	6.0	-99.00	8.1
830421	17.0	150.	1710	0	7.5	9.2	11.0	14	14	22.	29.22	90	200000	7.0	3.20	8.1
830505	13.0	54.	1940	0	7.5	12.0	13.0	20	14	21.	41.13	74	300000	11.0	3.60	7.5
830505	13.0	100.	1910	0	7.4	8.3	13.0	12	12	21.	44.09	67	500000	11.0	3.20	7.6
830519	13.0	95.	2070	0	7.7	12.0	12.0	20	20	20.	49.29	100	100000	8.0	5.20	7.9
830602	9.3	130.	2190	0	7.7	10.0	12.0	0	0	17.	28.56	89	300000	13.0	1.80	6.9
830602	9.6	100.	2190	0	7.7	10.0	12.0	0	0	18.	28.56	90	100000	13.0	1.20	6.8
830616	12.0	100.	2300	.10	7.7	10.0	11.0	10	10	15.	50.66	57	200000	15.5	.10	7.2
830630	7.7	110.	2200	.10	7.9	10.0	11.0	10	10	13.	47.81	30	100000	18.0	.50	8.0
830630	6.9	110.	2300	.10	7.7	9.3	11.0	12	12	14.	48.70	35	300000	17.0	.60	8.0
830714	7.4	76.	2280	0	7.6	9.0	9.0	22	16	14.	28.98	61	1030000	21.0	.60	7.9
830728	6.4	97.	2190	0	7.9	8.6	9.0	20	20	13.	28.87	56	450000	21.0	1.80	7.5
830728	6.2	120.	2220	0	7.9	9.0	9.0	22	22	13.	29.33	56	480000	21.0	1.60	7.5

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TABLE 21. PLOT 1 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810730	12.0	13.	2080	.15	8.2	6.8	7.4	12	12	11.	-99.00	30	142000	-99.0	-99.00	-99.0
810806	13.0	15.	1950	.13	7.6	11.0	13.0	4	0	16.	-99.00	34	96000	19.0	1.00	-99.0
810903	2.9	8.	1730	2.90	8.1	4.7	5.1	2	2	5.	13.06	13	1200000	15.0	4.10	7.2
810917	24.0	27.	1710	.07	7.5	11.0	11.0	10	10	27.	21.58	42	50000000	16.0	2.10	7.5
810917	24.0	37.	1710	.08	7.9	10.0	11.0	6	6	27.	29.34	51	70000000	16.0	2.10	7.5
811006	18.0	50.	1520	.04	7.7	15.0	15.0	6	6	18.	23.10	24	40000000	14.0	2.80	7.1
811022	11.0	48.	1570	1.90	7.8	8.6	11.0	6	6	15.	25.61	20	27000000	6.0	11.00	8.0
811105	10.0	36.	1640	28.00	7.8	11.0	13.0	6	6	14.	14.71	19	730000	5.0	6.80	7.7
811105	11.0	38.	1650	25.00	7.9	11.0	13.0	6	6	14.	11.01	19	560000	5.0	6.80	7.7
811119	14.0	50.	1570	2.01	7.8	12.0	13.0	40	18	20.	16.50	21	1200000	3.0	5.00	7.5
811203	24.0	53.	1510	.92	7.9	15.0	18.0	14	6	28.	42.63	69	1100000	0	12.90	7.8
811203	25.0	78.	1490	.24	7.9	15.0	19.0	14	8	28.	40.73	70	4000000	0	12.70	7.8
811217	17.0	68.	1560	.61	8.0	18.0	19.0	14	8	24.	-99.00	98	1630000	0	7.20	7.8
811230	14.0	45.	1600	.10	7.7	14.0	14.0	4	2	17.	16.62	40	250000	1.0	7.00	7.5
811230	13.0	43.	1620	.10	7.7	13.0	13.0	6	4	17.	15.42	41	250000	1.0	7.20	7.6
820114	24.0	120.	1650	0	7.8	16.0	16.0	34	12	35.	28.40	76	800000	1.0	-99.00	7.6
820128	23.0	140.	1610	0	7.8	15.0	15.0	130	42	32.	33.11	97	150000	1.0	6.50	7.9
820128	23.0	140.	1810	0	7.8	18.0	19.0	150	36	31.	38.33	98	165000	1.0	6.00	7.3
820211	28.0	220.	1770	0	8.1	24.0	28.0	24	22	45.	47.01	150	880000	0	6.80	-99.0
820225	12.0	130.	883	0	8.0	10.0	11.0	18	18	18.	19.61	79	280000	1.0	8.30	-99.0
820225	12.0	79.	884	0	8.0	10.0	19.0	12	12	18.	20.82	80	310000	0	8.60	-99.0
820311	18.0	100.	1670	0	7.9	12.0	20.0	16	16	23.	32.12	62	1130000	5.0	4.20	-99.0
820506	22.0	58.	1510	.10	7.7	12.0	13.0	2	2	22.	19.26	29	1130000	11.0	3.00	7.6
820506	22.0	66.	1500	.10	7.8	14.0	14.0	0	0	22.	19.29	27	1250000	11.0	3.50	7.6
820520	7.7	67.	1710	8.70	7.7	13.0	15.0	0	0	10.	18.11	11	480000	14.0	4.80	7.8
820603	18.0	57.	1790	.80	7.7	11.0	15.0	8	6	20.	24.22	45	1400000	17.0	2.00	7.7
820603	18.0	53.	1790	1.80	7.7	11.0	14.0	4	4	20.	23.32	49	1400000	17.0	2.10	7.7
820617	5.7	76.	1760	1.10	7.4	10.0	14.0	10	10	12.	27.30	16	600000	20.0	-99.00	7.7
820701	1.2	28.	2000	7.70	7.7	11.0	12.0	8	4	5.	14.70	9	200000	18.0	4.40	7.7
820701	1.2	28.	2000	7.80	7.7	11.0	11.0	6	2	4.	14.00	11	300000	18.5	4.40	7.7
820715	11.0	67.	2150	.30	7.7	13.0	16.0	38	18	15.	29.05	45	20000	26.0	1.50	7.5
820805	7.4	72.	2080	.50	7.5	14.0	14.0	4	2	10.	15.71	20	1510000	22.0	1.70	7.4
820805	7.4	77.	2080	.70	7.5	14.0	14.0	6	4	11.	18.41	20	1080000	22.0	1.60	7.3
820902	6.6	58.	1970	.90	7.5	9.3	10.0	18	10	9.	13.32	22	300000	20.0	2.00	7.5
820916	12.0	240.	1770	.20	7.6	18.0	18.0	970	360	15.	21.00	86	1000000	14.5	3.10	7.5
820916	12.0	180.	1740	8.30	7.7	12.0	16.0	332	106	14.	17.00	40	1700000	15.0	.40	7.5
820930	4.9	33.	1610	14.00	7.8	8.8	12.0	52	22	8.	14.00	19	8200000	7.5	4.25	7.1
821014	12.0	43.	1630	15.00	7.8	22.0	22.0	10	10	13.	12.70	20	1100000	10.0	5.70	7.3
821014	[illegible]	43.	1650	16.00	7.8	12.0	16.0	16	12	13.	11.60	18	1300000	9.0	5.50	7.3
821028	[illegible]	330.	1380	12.00	7.9	20.0	21.0	132	54	14.	17.60	37	1000000	3.0	4.40	7.3
821110	12.0	23.	1880	17.00	7.6	12.0	18.0	42	20	15.	9.49	23	1000000	6.0	5.60	-99.0
821118	21.0	5.	1700	17.00	7.7	12.0	12.0	20	12	22.	13.08	39	1100000	4.0	2.20	6.8
821118	22.0	3.	1680	17.00	7.7	12.0	19.0	20	12	25.	13.93	30	1500000	3.0	2.30	6.8
821202	16.0	67.	1590	15.00	7.7	11.0	13.0	6	2	19.	21.19	43	600000	0	7.50	6.8
821216	19.0	180.	1520	4.60	7.9	11.0	18.0	14	8	26.	22.15	72	1500000	1.0	5.40	7.1
821216	20.0	160.	1480	23.00	7.9	10.0	18.0	8	2	26.	30.94	74	800000	1.0	5.60	7.2
821230	18.0	84.	1970	15.00	7.7	12.0	14.0	2	0	20.	23.06	42	400000	0	4.00	6.7
830113	19.0	79.	1420	0	7.7	12.0	14.0	12	4	22.	27.66	48	1600000	2.0	4.20	7.4
830113	18.0	79.	1420	0	7.7	12.0	15.0	32	20	22.	27.01	44	700000	2.0	3.70	7.1
830127	27.0	160.	1380	11.00	7.8	14.0	17.0	66	38	32.	29.25	110	700000	2.0	3.00	6.3
830210	19.0	74.	1380	27.00	7.6	11.0	12.0	2	0	20.	22.69	110	900000	0	2.30	6.6
830210	18.0	89.	1470	0	7.6	12.0	12.0	8	4	20.	16.73	100	800000	0	2.30	6.6
830224	18.0	140.	1230	.10	7.9	14.0	15.0	18	16	22.	43.41	130	800000	2.0	7.10	6.6
830310	14.0	230.	1530	.10	7.5	11.0	15.0	150	94	26.	66.29	140	1100000	8.0	2.10	6.8
830310	14.0	290.	1520	.10	7.5	11.0	13.0	78	62	26.	80.97	100	1500000	8.0	2.10	6.8
830324	21.0	56.	1740	.34	7.7	9.4	19.0	2	2	21.	20.06	36	1000000	7.0	2.80	7.2
830407	20.0	46.	1750	0	7.6	9.3	18.0	12	2	20.	22.75	35	400000	3.0	-99.00	8.0
830407	20.0	48.	1770	0	7.7	8.4	17.0	6	6	20.	20.40	32	300000	3.0	-99.00	8.0
830421	12.0	80.	1610	.30	7.4	8.6	10.0	42	30	15.	19.15	30	800000	2.0	4.80	8.2
830505	8.4	40.	2400	51.00	7.6	8.4	13.0	70	30	14.	25.28	23	1100000	13.0	5.30	7.5
830505	8.0	65.	2390	2.60	7.7	8.3	13.0	28	16	13.	22.20	23	700000	13.0	5.40	7.5
830519	6.1	10.	2300	5.00	7.7	7.5	7.5	2	0	9.	25.07	23	700000	9.0	8.40	7.9
830602	1.7	100.	2580	0	7.5	9.0	9.8	460	72	6.	19.66	32	400000	15.5	3.80	6.8
830602	1.3	250.	2570	.20	7.5	8.9	9.7	4	0	6.	19.40	22	100000	16.0	3.60	6.9
830616	3.2	78.	2610	1.80	7.5	8.5	8.9	10	10	4.	29.04	14	100000	18.0	2.30	7.2
830630	8.3	83.	2380	1.60	7.6	9.6	10.0	34	28	12.	33.76	18	420000	21.0	2.20	7.8
830630	7.7	78.	2380	2.80	7.6	10.0	11.0	22	20	16.	40.44	16	500000	21.5	1.80	7.8
830714	4.3	37.	2420	0	7.6	7.1	7.1	0	0	7.	17.81	16	630000	23.0	2.10	7.9
830728	4.8	48.	2410	.40	7.9	8.2	9.0	4	4	8.	18.48	18	480000	22.0	4.40	7.5
830728	4.8	56.	2400	.40	7.9	8.6	8.6	4	4	9.	17.77	22	480000	23.0	4.00	7.5

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TABLE 22. PLOT 2 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810730	10.0	14.	1940	.05	7.5	10.0	11.0	8	8	14.	-99.00	34	149000	-99.0	-99.00	-99.0
810806	12.0	15.	1920	.29	7.6	12.0	13.0	4	4	14.	-99.00	35	108000	18.0	1.00	-99.0
811006	13.0	43.	1630	.23	7.8	8.5	8.9	0	0	15.	16.93	10	30000000	13.0	5.50	6.9
811006	18.0	43.	1610	.13	7.8	9.0	9.6	0	0	18.	18.13	6	30000000	13.0	5.40	7.1
811022	5.5	66.	1600	.32	7.9	8.8	9.8	2	0	12.	22.08	21	35000000	6.0	11.00	7.5
811105	9.6	34.	1620	21.00	7.9	10.0	12.0	10	10	14.	14.89	20	790000	6.0	6.00	7.2
811119	15.0	40.	1690	2.43	7.8	13.0	13.0	24	12	21.	19.08	28	5000000	3.0	6.20	7.7
811119	16.0	46.	1690	2.24	7.9	13.0	14.0	72	40	21.	19.54	25	6000000	3.0	6.20	7.7
811203	25.0	58.	1480	.29	8.0	14.0	21.0	6	4	30.	43.43	70	980000	0	13.60	7.9
811217	21.0	140.	2040	.97	8.1	23.0	26.0	48	34	31.	-99.00	150	1420000	0	10.50	8.1
811217	21.0	130.	1990	.86	8.1	23.0	28.0	36	26	31.	-99.00	150	1500000	0	10.60	8.1
811230	15.0	59.	1510	0	7.9	16.0	16.0	8	6	18.	19.01	65	250000	2.0	9.00	7.8
820128	23.0	150.	1460	0	8.0	16.0	18.0	78	36	34.	41.54	120	1400000	1.0	8.00	7.5
820211	25.0	130.	1370	0	7.9	15.0	17.0	30	26	36.	28.64	120	1040000	0	4.40	-99.0
820211	25.0	150.	1370	0	7.9	15.0	16.0	20	18	36.	25.84	120	970000	0	4.60	-99.0
820225	15.0	75.	1220	0	8.0	13.0	15.0	110	28	24.	21.05	82	340000	0	8.80	-99.0
820311	16.0	58.	1640	0	8.0	13.0	16.0	64	36	23.	39.27	62	1110000	3.0	4.40	-99.0
820311	16.0	63.	1640	.10	8.0	13.0	26.0	82	34	23.	41.07	62	1040000	3.0	4.50	-99.0
820506	17.0	50.	1570	.60	8.0	11.0	12.0	0	0	17.	16.28	23	680000	10.0	6.00	7.8
820520	8.7	37.	2010	7.70	7.7	11.0	14.0	2	2	11.	12.24	8	600000	14.0	4.10	7.8
820520	9.4	47.	2020	5.20	7.7	11.0	14.0	0	0	11.	13.37	10	660000	14.0	4.20	7.8
820603	17.0	62.	1800	.40	7.7	11.0	14.0	6	6	18.	24.86	42	1000000	17.0	2.30	7.7
820617	2.2	83.	1800	.50	7.6	12.0	15.0	76	26	10.	33.20	22	300000	21.0	-99.00	7.7
820617	13.0	100.	1860	.40	7.7	12.0	16.0	6	6	20.	44.51	22	400000	17.0	-99.00	7.7
820701	5.4	42.	2080	.30	7.6	12.0	14.0	36	10	8.	21.10	13	100000	19.0	2.60	7.6
820715	14.0	100.	2220	.20	7.7	16.0	18.0	30	14	19.	32.40	50	20000	26.0	.80	7.6
820715	14.0	87.	2210	1.40	7.8	15.0	19.0	30	14	19.	33.00	49	10000	25.5	1.00	7.7
820805	2.2	87.	2120	.30	7.6	17.0	17.0	56	22	11.	32.29	31	250000	21.0	1.90	7.1
820902	4.3	75.	1910	1.10	7.6	11.0	17.0	160	94	18.	26.83	51	400000	19.5	2.20	7.5
820902	3.7	100.	1970	0	7.6	16.0	21.0	430	124	27.	31.57	72	550000	19.0	2.20	7.5
820916	5.1	150.	1490	4.60	7.8	12.0	15.0	40	20	10.	26.00	42	1500000	15.0	3.30	7.7
820930	5.7	17.	1870	14.00	7.7	5.6	9.2	32	22	11.	14.00	23	4200000	7.0	2.90	7.0
820930	4.5	220.	1770	2.70	7.7	7.1	14.0	632	150	16.	14.00	17	2100000	7.0	2.80	7.0
821014	7.0	110.	1680	8.80	7.7	19.0	20.0	150	54	11.	15.50	24	1100000	10.0	6.00	7.5
821028	8.1	120.	1450	10.00	7.9	15.0	15.0	52	28	11.	15.80	30	900000	2.0	4.00	7.4
821028	7.7	110.	1510	4.30	8.0	14.0	15.0	56	30	11.	18.30	29	1500000	2.0	4.00	7.4
821110	8.3	20.	1590	16.00	8.0	8.8	15.0	12	12	10.	6.92	19	800000	5.0	8.40	-99.0
821110	8.3	21.	1590	16.00	8.0	7.2	21.0	14	10	10.	6.44	19	800000	5.0	8.60	-99.0
821118	15.0	6.	1520	15.00	8.0	15.0	17.0	6	0	16.	10.60	25	1100000	1.0	7.70	7.0
821202	20.0	160.	1730	.10	8.1	17.0	20.0	26	20	26.	36.24	76	2100000	0	10.00	6.9
821202	20.0	130.	1700	2.00	8.1	17.0	19.0	8	4	26.	37.49	76	1000000	0	10.00	7.0
821216	22.0	180.	1450	24.00	7.8	17.0	25.0	14	8	29.	40.39	92	800000	0	4.40	7.2
821230	19.0	82.	2060	17.00	7.7	12.0	14.0	2	0	22.	25.41	52	200000	0	4.40	6.7
821230	19.0	91.	2300	2.00	7.8	13.0	14.0	12	4	22.	25.86	54	300000	0	4.40	6.7
830113	22.0	100.	1340	0	7.7	13.0	16.0	18	12	27.	33.52	58	1600000	2.0	3.80	7.1
830127	24.0	560.	1280	30.00	7.8	13.0	15.0	26	18	32.	38.93	120	600000	1.5	3.20	6.3
830127	25.0	160.	1380	14.00	7.8	14.0	14.0	22	16	31.	43.91	110	700000	1.5	3.20	6.3
830210	24.0	100.	1400	0	7.7	13.0	14.0	2	2	25.	19.87	110	1600000	0	2.60	6.6
830224	19.0	150.	1320	.10	7.7	15.0	16.0	14	14	24.	45.66	120	1000000	2.0	6.40	6.6
830224	21.0	170.	1320	.10	7.7	13.0	17.0	10	10	24.	44.40	120	600000	2.0	6.30	6.6
830310	12.0	140.	1660	5.30	7.6	10.0	11.0	30	22	19.	32.16	50	700000	8.0	2.10	6.7
830324	18.0	52.	1660	1.00	7.8	9.6	19.0	0	0	18.	19.36	29	400000	3.0	4.80	7.2
830324	18.0	44.	1680	.25	7.8	10.0	20.0	2	2	18.	18.87	35	300000	3.0	5.00	7.2
830407	18.0	56.	1770	0	7.9	10.0	20.0	2	2	18.	21.13	31	100000	2.0	-99.00	7.9
830421	13.0	74.	1590	12.00	7.9	9.2	11.0	20	20	16.	22.55	30	400000	2.0	7.70	8.5
830421	13.0	230.	1690	0	7.0	8.7	8.7	116	70	20.	31.87	42	1100000	3.0	8.20	8.1
830505	2.1	24.	2530	0	8.4	7.1	13.0	26	16	8.	25.97	24	100000	13.0	11.80	7.6
830519	1.0	42.	2280	3.60	8.4	6.8	7.8	110	58	9.	41.05	28	500000	9.0	14.40	8.1
830519	1.0	88.	2280	4.30	8.4	5.6	7.9	30	20	10.	33.05	18	100000	9.0	14.20	8.2
830602	2.4	140.	2530	0	7.4	14.0	16.0	110	58	15.	39.72	34	100000	18.0	7.80	6.9
830616	1.9	27.	2640	2.60	7.6	8.1	8.6	0	0	3.	29.35	17	100000	19.0	2.80	7.2
830616	1.9	49.	2680	2.80	7.6	8.5	8.9	6	6	2.	30.32	14	100000	19.0	3.40	7.2
830630	4.6	77.	2450	.10	7.7	8.9	9.3	14	14	10.	31.82	17	210000	22.0	2.20	7.8
830714	4.1	66.	2360	.10	7.6	7.1	7.1	0	0	7.	17.12	12	100000	22.0	2.00	7.9
830714	4.1	62.	2390	4.60	7.5	7.1	7.1	0	0	7.	17.18	10	80000	22.0	2.00	8.0
830728	4.4	47.	2380	.60	7.7	7.5	7.5	2	2	8.	16.91	15	650000	21.0	3.40	7.5

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TABLE 23. PLOT 3 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810806	9.2	15.	2090	.07	8.0	10.0	12.0	4	4	13.	-99.00	23	1400	18.0	1.60	-99.0
810903	10.0	25.	1830	.04	7.1	9.2	9.8	12	12	11.	25.58	58	960000	16.0	4.50	7.3
810917	8.7	23.	1710	1.60	7.5	9.5	10.0	10	10	14.	23.80	33	20000000	14.0	14.10	7.5
810917	8.7	8.	1720	1.70	7.8	9.9	10.0	8	8	9.	23.39	30	1800000	14.0	4.00	7.5
811006	13.0	43.	1620	.52	7.8	10.0	11.0	26	26	15.	14.87	8	20000000	12.0	5.40	6.9
811022	7.4	45.	1620	.95	7.8	9.7	11.0	14	8	12.	17.17	26	52000000	5.5	11.40	7.6
811105	12.0	76.	1510	20.00	7.9	12.0	14.0	12	12	15.	18.09	39	120000	4.0	7.20	7.6
811119	16.0	56.	1620	2.88	7.8	13.0	14.0	4	4	16.	17.25	31	600000	1.0	7.00	7.7
811203	21.0	67.	1540	.06	7.5	17.0	17.0	16	2	27.	48.44	83	600000	0	12.90	7.4
811217	21.0	80.	1590	.17	7.9	17.0	22.0	20	14	27.	-99.00	95	1100000	0	9.00	7.8
811217	21.0	82.	1590	.18	7.9	17.0	18.0	18	12	27.	-99.00	92	610000	0	9.20	7.9
811230	19.0	71.	1580	0	7.8	16.0	16.0	14	10	26.	25.05	98	240000	.5	7.50	7.3
820114	22.0	140.	1610	0	7.8	16.0	16.0	14	2	30.	44.38	91	248000	1.0	-99.00	7.5
820128	21.0	130.	1390	0	7.9	15.0	18.0	84	30	27.	29.46	96	300000	1.0	4.80	7.6
820211	23.0	150.	1490	0	7.7	17.0	18.0	20	18	31.	25.89	130	710000	0	4.60	-99.0
820211	23.0	170.	1480	0	7.7	16.0	18.0	28	26	32.	28.66	130	700000	0	4.30	-99.0
820225	18.0	77.	1290	0	7.9	14.0	16.0	18	18	25.	22.90	79	110000	1.0	6.00	-99.0
820311	18.0	50.	1300	0	7.9	13.0	17.0	18	18	22.	28.59	64	400000	4.0	6.20	-99.0
820506	16.0	96.	1550	1.50	8.0	15.0	16.0	6	2	20.	33.16	56	380000	10.0	5.50	7.8
820520	7.0	90.	1530	7.80	7.8	14.0	17.0	2	2	14.	28.24	40	180000	14.0	5.80	7.9
820520	8.1	82.	1530	7.80	7.8	13.0	18.0	4	4	14.	29.78	42	180000	14.0	5.90	7.9
820603	5.5	85.	1690	.10	7.8	13.0	16.0	36	24	17.	30.12	74	210000	18.0	4.30	7.8
820617	5.3	85.	1790	0	7.8	12.0	13.0	2	2	11.	31.51	50	170000	20.0	-99.00	7.9
820701	5.6	45.	1830	.70	7.7	13.0	15.0	4	0	10.	20.50	22	100000	19.0	3.40	7.8
820715	12.0	84.	1920	0	7.8	13.0	16.0	12	8	17.	31.50	42	6000	24.0	2.30	7.7
820713	12.0	79.	1900	.90	7.8	13.0	17.0	8	6	16.	30.60	41	4000	24.0	2.30	7.7
820805	4.8	87.	1830	.90	7.8	13.0	13.0	28	26	11.	24.38	18	117000	22.0	3.20	7.7
820902	9.2	92.	1740	0	7.6	14.0	14.0	26	18	16.	25.56	43	140000	19.0	2.20	7.5
820916	12.0	120.	1570	10.00	7.7	11.0	15.0	8	8	13.	16.00	38	160000	13.0	2.70	7.6
820930	13.0	73.	1620	11.00	7.7	11.0	14.0	12	12	15.	15.00	50	640000	7.0	2.60	7.0
820930	13.0	83.	1620	11.00	7.8	11.0	15.0	12	12	15.	17.00	54	720000	7.0	2.80	7.0
821014	6.2	220.	1500	7.00	7.8	22.0	23.0	94	58	14.	22.20	69	370000	9.0	6.30	7.7
821028	10.0	98.	1540	14.00	7.8	19.0	19.0	12	10	14.	18.90	40	240000	3.5	3.80	7.4
821110	14.0	18.	1530	18.00	7.7	16.0	16.0	12	12	16.	10.94	46	250000	5.0	6.40	-99.0
821118	17.0	35.	1490	2.20	8.0	15.0	17.0	0	0	19.	14.87	50	360000	0	6.50	7.0
821118	17.0	61.	1420	17.00	7.8	15.0	16.0	8	6	19.	14.51	52	280000	0	6.40	7.0
821202	20.0	140.	1540	20.00	8.1	15.0	19.0	14	10	25.	29.45	82	460000	0	10.40	7.2
821216	21.0	190.	1560	16.00	8.0	13.0	19.0	10	8	26.	21.06	86	150000	1.0	6.30	7.1
821230	32.0	130.	2200	.20	7.9	16.0	23.0	14	8	35.	54.41	130	120000	0	3.40	6.7
830113	22.0	120.	1530	0	7.9	16.0	20.0	30	26	26.	41.50	76	60000	1.5	5.00	7.5
830113	22.0	130.	1530	0	7.8	16.0	21.0	28	26	25.	42.71	81	70000	1.5	5.90	7.2
830127	24.0	190.	1340	30.00	7.9	15.0	15.0	6	6	25.	17.21	110	100000	3.0	4.90	6.2
830210	26.0	130.	1470	0	7.5	16.0	16.0	6	6	26.	42.93	140	340000	2.0	3.60	6.6
830224	20.0	140.	1280	.10	7.6	12.0	16.0	24	20	24.	30.82	120	200000	5.0	3.60	6.5
830310	15.0	140.	1250	.10	7.7	13.0	15.0	48	24	21.	34.73	82	180000	2.0	2.80	7.0
830310	16.0	140.	1250	.10	7.6	14.0	15.0	14	12	22.	33.12	76	140000	2.0	2.60	6.9
830324	18.0	64.	1290	3.10	7.8	11.0	27.0	4	4	21.	22.33	45	110000	3.0	3.40	7.2
830407	20.0	120.	1560	0	7.7	10.0	20.0	26	18	21.	28.04	49	40000	4.0	-99.00	7.9
830421	13.0	62.	1440	12.00	7.7	9.0	9.2	10	10	16.	20.23	44	80000	2.0	6.00	8.1
830505	8.1	92.	1840	.10	7.8	10.0	10.0	10	6	12.	29.26	50	220000	12.0	8.20	7.6
830505	7.9	28.	1840	0	7.8	10.0	10.0	10	6	12.	29.19	49	10000	12.0	8.00	7.6
830519	2.6	62.	1910	4.20	7.9	9.1	9.5	6	4	10.	39.14	49	20000	8.5	11.20	8.1
830602	1.8	600.	2150	0	7.8	8.7	9.6	0	0	8.	25.48	55	140000	17.0	7.00	7.0
830616	2.5	30.	2240	.30	7.7	10.0	11.0	4	4	3.	40.95	26	70000	20.0	4.90	7.3
830630	1.0	120.	2330	3.50	7.8	8.9	9.3	8	8	5.	30.63	12	10000	22.0	4.20	7.9
830630	1.0	96.	2330	3.20	7.8	8.5	8.9	12	12	5.	31.29	12	10000	22.0	3.60	8.0
830714	1.9	100.	2020	2.90	7.7	9.7	9.7	2	2	5.	22.59	11	23000	24.0	3.20	7.9
830728	3.2	80.	2180	.50	7.8	9.3	9.3	0	0	7.	24.95	8	34000	21.0	3.60	7.5

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TABLE 24. PLOT 4 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810806	7.5	13.	2140	.14	8.0	9.0	10.0	4	4	11.	-99.00	24	600	18.0	2.20	-99.0
810821	2.9	25.	2230	1.40	8.4	3.1	3.1	2	0	3.	19.14	32	160000	22.0	4.80	7.9
810903	5.9	27.	2010	3.10	7.5	6.7	6.7	12	12	7.	25.48	46	1120000	17.0	5.50	7.3
810917	7.2	17.	1760	1.20	7.6	7.4	7.8	8	8	14.	20.27	24	5800000	17.0	6.50	7.6
811006	13.0	45.	1720	.07	7.8	8.6	9.7	4	4	15.	17.55	10	15000000	14.0	6.50	7.3
811006	13.0	50.	1720	.09	7.8	9.1	9.6	4	4	15.	17.11	8	9100000	14.0	6.60	7.3
811022	9.6	48.	1580	.09	7.7	11.0	14.0	0	0	10.	13.42	36	18000000	6.0	10.60	7.6
811022	13.0	64.	1630	.10	7.7	9.1	12.0	0	0	15.	16.49	33	52000000	6.0	11.00	7.6
811105	11.0	89.	1610	6.39	7.9	12.0	13.0	8	8	15.	18.00	39	180000	5.5	6.00	7.6
811105	12.0	130.	1630	3.34	7.8	11.0	13.0	14	12	16.	18.07	38	360000	6.0	6.00	7.4
811119	16.0	60.	1640	1.01	7.7	13.0	13.0	6	6	18.	20.14	36	400000	1.0	6.10	7.7
811203	23.0	70.	1710	.07	7.9	17.0	17.0	174	172	26.	45.91	80	230000	0	11.40	7.8
811217	21.0	78.	1540	.15	7.9	16.0	18.0	10	6	26.	-99.00	92	750000	0	10.00	7.8
811230	20.0	71.	1590	0	7.8	16.0	16.0	14	8	25.	25.70	95	240000	0	8.00	7.3
811230	19.0	71.	1590	0	7.7	16.0	16.0	18	14	25.	22.99	95	222000	0	9.50	7.3
820114	21.0	140.	1550	0	7.8	10.0	10.0	14	2	27.	27.97	87	1200000	2.0	-99.00	7.5
820128	21.0	150.	1430	0	7.8	15.0	16.0	32	22	27.	27.99	97	700000	1.0	2.80	7.6
820211	24.0	160.	1490	0	7.6	17.0	17.0	22	20	32.	25.73	130	830000	0	4.60	-99.0
820225	19.0	75.	1310	0	7.7	14.0	17.0	34	24	26.	18.69	89	110000	1.0	5.20	-99.0
820225	19.0	80.	1310	0	8.0	14.0	16.0	60	28	26.	17.23	85	240000	1.0	4.60	-99.0
820311	18.0	60.	1310	0	7.9	13.0	18.0	16	16	23.	33.28	71	330000	4.0	5.80	-99.0
820506	14.0	100.	1550	2.50	8.2	12.0	14.0	2	2	17.	33.50	58	500000	10.0	9.00	7.6
820520	7.9	79.	1550	7.60	8.0	13.0	17.0	2	2	14.	28.52	45	100000	14.0	11.30	8.1
820603	3.0	84.	1720	1.70	8.0	13.0	16.0	26	22	12.	32.93	83	210000	17.0	8.00	8.0
820603	2.9	84.	1720	.10	8.0	13.0	17.0	22	22	13.	32.36	86	240000	17.0	8.10	8.0
820617	4.2	83.	1840	.40	7.7	11.0	12.0	10	10	9.	30.51	48	100000	19.0	-99.00	7.9
820701	4.6	48.	1860	1.20	7.6	12.0	13.0	6	2	9.	19.60	17	100000	18.0	4.00	7.7
820715	12.0	92.	1940	2.20	7.8	14.0	18.0	8	6	19.	33.80	54	10000	25.0	2.80	7.7
820805	4.1	67.	1870	.30	7.7	12.0	12.0	100	22	7.	22.01	12	20000	23.0	3.70	7.7
820805	4.2	70.	1870	.30	7.7	12.0	12.0	18	18	9.	23.14	10	18000	23.0	3.80	7.7
820902	4.2	70.	1760	.50	7.6	12.0	12.0	14	10	8.	18.26	31	19000	17.0	3.40	7.5
820916	10.0	55.	1640	8.90	7.7	12.0	14.0	42	18	12.	13.00	36	150000	13.0	3.40	7.6
820930	10.0	40.	1650	8.70	7.8	11.0	13.0	32	16	12.	14.00	45	950000	7.0	3.25	7.0
821014	13.0	85.	1570	15.00	7.9	21.0	22.0	26	16	16.	18.50	46	330000	10.0	5.70	7.4
821014	13.0	140.	1550	14.00	7.9	16.0	16.0	18	14	17.	18.90	48	390000	10.0	6.00	7.6
821028	11.0	93.	1500	13.00	8.1	18.0	18.0	12	10	14.	18.20	40	190000	2.0	4.20	7.5
821110	12.0	17.	1500	16.00	7.8	13.0	19.0	4	4	14.	11.36	46	240000	4.0	7.70	-99.0
821118	16.0	41.	1440	16.00	7.9	14.0	17.0	6	6	19.	15.33	52	530000	1.0	5.90	7.0
821202	19.0	110.	1590	32.00	8.1	15.0	18.0	8	6	25.	33.49	86	450000	0	8.60	7.2
821202	20.0	97.	1580	33.00	8.1	14.0	18.0	10	0	25.	31.68	83	490000	0	8.60	7.3
821216	20.0	170.	1470	21.00	8.1	12.0	16.0	16	10	26.	27.22	84	280000	0	4.20	7.2
821230	28.0	150.	1800	0	7.7	16.0	21.0	10	6	29.	50.12	120	100000	0	2.00	6.7
830113	22.0	110.	1510	0	7.8	16.0	20.0	20	14	25.	38.99	73	220000	2.0	4.80	7.3
830127	25.0	80.	1450	0	7.8	15.0	16.0	12	8	26.	30.41	110	250000	3.0	2.60	6.3
830127	22.0	110.	1350	34.00	7.8	15.0	16.0	6	6	26.	19.65	100	200000	3.0	2.80	6.3
830210	25.0	140.	1460	0	7.6	15.0	15.0	8	8	26.	40.82	140	270000	1.0	3.20	6.6
830224	19.0	97.	1250	.10	7.7	13.0	14.0	14	12	22.	31.62	100	250000	4.0	2.80	6.6
830310	13.0	78.	1230	.10	7.6	13.0	13.0	16	16	20.	25.80	55	30000	2.0	3.20	7.0
830324	23.0	160.	1490	0	7.7	9.4	26.0	88	58	24.	30.72	69	250000	8.0	1.90	7.1
830324	22.0	180.	1500	0	7.8	14.0	21.0	84	60	24.	33.38	87	240000	8.0	2.10	7.1
830407	21.0	120.	1610	0	7.7	13.0	25.0	24	6	21.	26.27	58	50000	8.0	-99.00	7.8
830421	15.0	74.	1470	8.50	7.6	9.2	9.6	14	10	17.	23.13	50	170000	3.0	5.30	8.1
830505	7.3	130.	1870	0	7.8	9.7	9.9	16	10	13.	39.95	52	10000	12.0	8.70	7.7
830519	3.3	99.	1950	3.10	7.9	9.1	9.5	4	4	10.	39.41	49	40000	8.5	11.60	8.1
830519	3.4	70.	1960	2.80	8.0	9.0	9.5	6	4	10.	42.19	50	10000	9.0	11.50	8.1
830602	1.8	100.	2150	.20	7.8	8.2	9.2	2	2	8.	23.89	59	60000	17.0	9.40	7.1
830616	3.3	64.	2270	2.40	7.8	10.0	11.0	4	4	6.	32.79	28	10000	20.0	6.80	7.3
830630	1.0	77.	2330	3.30	8.0	8.9	9.7	12	12	5.	31.11	16	20000	22.0	4.60	8.0
830714	3.2	83.	2320	2.90	7.6	9.3	9.3	2	2	7.	27.73	10	1000	24.0	3.80	8.0
830714	3.2	61.	2270	.40	7.7	9.3	9.3	2	2	7.	24.45	10	1000	24.0	3.20	8.0
830728	3.5	66.	2210	.30	7.8	9.3	9.3	8	8	8.	34.50	13	134000	21.0	3.60	7.5

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TABLE 25. PLOT 5 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810806	3.9	10.	2210	.08	7.7	3.8	4.4	12	12	6.	-99.00	19	100	18.0	2.00	-99.0
810821	1.3	23.	2050	.89	7.8	4.2	5.0	2	2	2.	18.60	27	106000	21.0	5.40	8.1
810903	6.5	38.	2050	3.20	7.7	4.2	4.4	4	4	8.	21.88	38	580000	18.0	6.10	7.6
811006	10.0	39.	1610	.02	7.8	7.9	8.9	8	8	14.	17.32	12	9800000	14.0	5.80	7.3
811022	8.9	45.	1510	.01	7.7	10.0	12.0	20	20	11.	15.52	35	90000000	7.0	10.60	7.7
811022	13.0	47.	1560	.01	7.6	11.0	15.0	24	24	14.	18.64	34	73000000	7.0	11.20	7.7
811119	5.7	50.	1750	3.32	8.0	10.0	11.0	16	14	10.	18.41	29	270000	1.0	9.40	7.6
811119	5.7	50.	1750	8.39	8.1	10.0	12.0	22	14	11.	18.83	29	400000	1.0	9.60	7.6
811203	21.0	67.	1600	.09	8.0	16.0	21.0	96	82	25.	47.19	74	440000	0	12.80	7.9
811217	22.0	100.	1810	.82	8.1	19.0	21.0	21	14	29.	-99.00	96	400000	0	9.70	8.0
811230	20.0	71.	1640	0	7.7	16.0	16.0	16	10	25.	21.63	100	170000	0	9.50	7.4
820114	21.0	150.	1550	0	7.5	15.0	16.0	62	26	29.	24.38	100	600000	1.0	-99.00	7.6
820114	22.0	150.	1560	0	7.6	16.0	16.0	62	32	29.	24.03	100	800000	1.0	-99.00	7.6
820128	22.0	140.	1440	0	7.8	15.0	17.0	40	30	27.	27.74	97	600000	1.0	2.40	7.3
820211	25.0	170.	1670	.20	7.9	18.0	19.0	70	30	34.	28.72	130	110000	0	6.40	-99.0
820225	6.0	82.	752	0	8.3	9.3	12.0	26	18	11.	13.22	56	1000	1.0	9.20	-99.0
820311	19.0	53.	1360	.20	8.0	13.0	24.0	20	20	23.	31.13	67	230000	4.0	6.20	-99.0
820311	19.0	57.	1350	0	7.9	12.0	22.0	14	14	22.	31.61	59	310000	5.0	6.00	-99.0
820520	12.0	70.	1520	9.10	7.9	12.0	16.0	4	4	16.	25.20	48	80000	13.5	8.20	8.1
820603	4.8	95.	1700	1.20	7.8	11.0	14.0	26	24	13.	31.43	73	300000	17.0	6.20	8.0
820617	.4	85.	1840	.50	7.8	9.4	10.0	110	30	9.	35.70	52	50000	17.0	-99.00	7.8
820617	.2	83.	1850	.20	7.8	9.5	11.0	180	34	8.	34.58	54	60000	17.0	-99.00	7.8
820701	1.0	50.	1960	2.80	7.6	8.8	9.7	44	10	6.	20.70	18	20000	16.0	3.00	7.7
820715	16.0	99.	2070	0	7.8	16.0	18.0	192	128	27.	37.20	77	13000	26.0	1.80	7.7
820805	1.2	110.	1940	1.20	7.8	11.0	11.0	38	28	9.	33.21	16	76000	25.0	2.80	7.7
820902	1.3	92.	1870	.20	7.9	8.8	10.0	182	50	4.	22.01	30	67000	16.0	4.90	7.8
820902	1.0	87.	1920	0	7.9	10.0	11.0	374	92	9.	27.37	40	72000	16.5	4.90	7.6
820916	3.2	75.	1610	4.30	8.0	7.7	12.0	12	8	5.	13.00	26	100000	15.0	5.80	7.6
820930	5.7	38.	1630	6.10	7.9	8.7	12.0	8	8	9.	14.00	35	610000	6.5	5.60	7.0
821014	5.0	190.	1580	6.10	8.0	19.0	19.0	40	20	11.	16.70	44	250000	9.0	7.80	7.7
821028	3.8	75.	1540	14.00	8.1	16.0	17.0	10	8	7.	15.10	30	270000	1.5	5.30	7.6
821028	3.6	100.	1540	14.00	8.1	16.0	16.0	16	14	7.	16.10	32	60000	2.0	5.20	7.5
821110	5.7	24.	1480	16.00	7.9	11.0	13.0	10	10	9.	8.91	35	180000	3.0	9.40	-99.0
821118	14.0	64.	1440	16.00	7.9	14.0	14.0	0	0	17.	14.09	44	220000	1.0	7.20	7.0
821202	20.0	99.	1510	30.00	8.1	11.0	18.0	12	0	24.	26.17	76	420000	0	10.10	7.4
821216	21.0	190.	1610	6.40	8.1	12.0	20.0	18	12	27.	30.32	93	180000	0	6.30	7.3
821216	21.0	350.	1700	.40	8.1	12.0	19.0	52	22	28.	34.53	100	130000	0	6.30	7.3
821230	28.0	160.	1830	0	7.7	16.0	21.0	12	8	29.	50.04	110	180000	0	2.40	6.8
830113	22.0	120.	1510	0	7.8	16.0	21.0	20	18	25.	41.23	80	160000	2.0	5.50	7.3
830127	24.0	110.	1330	37.00	7.8	7.5	15.0	234	34	25.	38.52	110	370000	3.0	2.50	6.3
830210	24.0	190.	1460	0	7.5	17.0	18.0	12	12	26.	42.75	130	270000	0	3.00	6.6
830210	25.0	170.	1450	0	7.9	17.0	18.0	6	4	26.	37.71	140	330000	0	3.00	6.6
830224	17.0	110.	1160	15.00	7.8	13.0	15.0	8	8	21.	26.82	98	210000	2.0	3.40	6.6
830310	14.0	88.	1240	7.60	7.7	13.0	14.0	80	34	21.	22.92	76	140000	2.0	2.80	7.0
830324	19.0	130.	1420	0	7.9	10.0	18.0	46	30	22.	41.14	67	80000	1.0	4.10	7.2
830407	19.0	120.	1480	0	7.8	11.0	18.0	22	8	21.	23.04	51	40000	3.0	-99.00	7.7
830407	19.0	120.	1500	0	7.8	11.0	21.0	22	8	20.	24.93	52	50000	1.0	-99.00	7.8
830421	12.0	67.	1510	1.00	7.9	8.4	9.0	8	8	16.	22.30	47	100000	1.0	5.70	8.0
830505	1.8	35.	1910	63.00	8.2	7.2	9.8	16	12	7.	33.07	35	50000	11.0	10.00	7.7
830519	1.0	86.	1860	3.00	8.0	7.6	8.5	120	30	7.	45.75	36	10000	7.0	11.10	8.1
830602	9.6	190.	2180	.20	7.8	6.9	8.0	0	0	18.	22.00	45	40000	16.0	9.20	7.1
830602	1.0	150.	2220	.30	7.9	7.1	8.0	0	0	5.	22.47	47	80000	16.0	8.20	7.2
830616	3.2	64.	2350	1.90	7.8	8.1	8.6	4	4	4.	31.39	22	50000	19.0	6.00	7.3
830630	1.0	150.	2290	.10	7.9	9.6	11.0	22	22	9.	35.69	14	10000	23.0	5.20	8.0
830714	1.0	50.	2330	4.70	7.9	4.1	7.5	0	0	2.	25.81	8	2000	25.0	3.40	8.1
830728	1.0	120.	2360	0	7.9	8.2	8.6	80	64	9.	35.01	21	36000	21.0	3.30	7.6
830728	1.0	97.	2420	0	7.9	8.2	8.6	90	68	10.	25.95	21	69000	21.0	3.20	7.6

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TABLE 26. PLOT 6 EFFLUENT CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	SUSP SOLID MG/L	VOL SOLID MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF /100ML	FIELD TEMP C	FIELD DO MG/L	FIELD PH
810806	10.0	46.	1900	.16	8.0	12.0	13.0	20	20	14.	-99.00	32	3000	20.0	3.40	-99.0
810821	9.5	38.	1860	.03	7.4	7.5	8.7	20	18	14.	36.15	67	200000	23.0	-99.00	8.9
810903	13.0	43.	1620	3.60	7.6	8.2	8.6	22	20	15.	39.84	75	1000000	21.0	10.00	8.9
810917	11.0	47.	1470	.13	8.4	6.3	6.7	12	12	19.	37.00	56	2800000	25.0	8.50	9.2
811006	8.1	87.	1480	.04	8.2	15.0	16.0	32	32	23.	62.01	57	14600000	18.0	7.60	7.7
811022	23.0	81.	1510	.07	8.1	15.0	18.0	6	6	33.	25.06	48	61000000	9.0	10.70	7.7
811105	26.0	130.	1500	3.26	8.0	16.0	17.0	58	18	26.	30.62	58	380000	8.0	6.10	7.8
811119	17.0	97.	1470	.06	8.1	14.0	16.0	12	12	24.	26.35	60	360000	1.0	8.80	7.8
811203	24.0	67.	1680	.06	7.9	16.0	17.0	20	10	29.	55.84	90	330000	0	11.80	7.9
811203	24.0	77.	1690	.04	7.9	18.0	20.0	18	8	28.	54.62	92	760000	0	11.80	7.9
811217	24.0	110.	1650	.08	7.9	18.0	18.0	28	18	29.	-99.00	120	490000	0	11.00	7.0
811230	21.0	86.	1560	0	7.7	15.0	16.0	24	10	26.	28.56	110	326000	0	7.50	7.2
820114	21.0	190.	1490	0	7.6	16.0	17.0	84	26	23.	22.66	100	1100000	1.0	-99.00	7.6
820128	22.0	150.	1450	0	7.9	15.0	17.0	110	36	28.	49.26	110	600000	1.0	5.40	7.4
820211	23.0	170.	1520	0	8.2	17.0	17.0	24	20	32.	25.63	130	590000	0	6.30	-99.0
820225	17.0	92.	1280	0	7.9	14.0	17.0	210	34	26.	16.54	75	140000	2.0	6.80	-99.0
820311	21.0	92.	1460	0	8.0	15.0	21.0	46	32	26.	40.00	70	320000	7.0	6.20	-99.0
820506	22.0	130.	1550	.20	8.1	18.0	18.0	64	42	26.	46.58	74	470000	11.0	7.50	8.0
820506	22.0	130.	1550	.20	8.1	17.0	19.0	66	46	26.	45.87	62	600000	11.0	7.50	8.0
820520	14.0	120.	1510	13.00	8.5	11.0	16.0	14	14	18.	35.61	66	150000	15.0	11.60	8.8
820603	11.0	90.	1710	.10	8.5	9.8	13.0	42	34	19.	34.32	81	320000	22.0	8.50	8.8
820617	6.2	91.	1740	0	8.7	6.3	8.6	18	18	14.	39.78	55	80000	23.0	-99.00	9.0
820701	5.8	50.	1760	.20	8.5	8.4	10.0	12	6	10.	24.00	24	40000	23.0	9.10	8.7
820701	1.0	53.	1760	.20	8.5	7.9	10.0	6	2	11.	24.10	21	30000	24.0	9.20	8.8
820715	11.0	82.	1880	.40	8.1	13.0	16.0	14	12	17.	31.58	44	5000	29.0	4.90	8.1
820805	6.3	110.	1800	.10	8.4	12.0	13.0	18	16	10.	29.89	22	112000	28.0	8.20	8.2
820902	4.1	75.	1700	.70	7.9	14.0	14.0	24	12	10.	29.16	44	101000	20.5	7.20	7.8
820916	13.0	60.	1580	11.00	8.0	13.0	17.0	12	12	15.	16.00	46	110000	15.0	7.00	7.7
820916	13.0	42.	1570	11.00	8.0	12.0	16.0	10	10	16.	16.00	41	100000	16.0	7.30	7.7
820930	15.0	120.	1150	11.00	7.9	12.0	16.0	12	12	18.	20.00	56	980000	6.5	6.00	7.1
821014	15.0	190.	1560	15.00	8.0	22.0	22.0	16	16	18.	18.80	44	250000	10.0	7.40	7.5
821028	16.0	100.	1630	.10	8.0	19.0	19.0	18	18	18.	19.70	40	130000	5.0	5.20	7.5
821110	18.0	31.	1590	7.20	7.9	15.0	15.0	8	8	20.	14.61	54	270000	6.0	9.10	-99.0
821110	17.0	40.	1530	17.00	7.9	15.0	16.0	20	18	21.	19.69	54	220000	6.0	8.80	-99.0
821118	19.0	63.	1420	17.00	7.9	14.0	19.0	4	4	21.	15.36	56	500000	2.0	6.20	7.1
821202	19.0	280.	1630	0	8.1	14.0	18.0	24	6	25.	29.07	80	240000	0	9.40	5.3
821216	22.0	170.	1590	13.00	8.0	12.0	18.0	8	6	27.	32.08	88	180000	0	5.00	7.4
821230	33.0	150.	2110	0	7.7	16.0	24.0	14	14	35.	55.33	120	70000	0	1.90	6.7
821230	29.0	150.	2110	0	7.6	15.0	24.0	20	14	35.	52.66	120	120000	0	1.80	6.7
830113	23.0	110.	1480	0	7.8	15.0	21.0	28	22	25.	41.39	72	230000	1.0	4.40	7.2
830127	26.0	100.	1390	0	7.7	16.0	16.0	10	10	27.	35.11	110	390000	4.0	2.00	6.3
830210	25.0	170.	1450	0	7.6	17.0	18.0	4	4	26.	37.27	150	340000	0	3.50	6.5
830224	15.0	110.	1200	6.50	7.8	13.0	15.0	14	12	21.	24.51	82	120000	2.0	3.70	6.6
830224	16.0	27.	1240	.10	7.7	13.0	15.0	16	14	24.	29.15	100	180000	4.0	2.20	6.6
830310	15.0	150.	1250	.10	7.6	9.1	11.0	8	8	24.	38.18	56	160000	2.0	3.80	7.0
830324	21.0	66.	1370	4.90	7.8	11.0	18.0	6	6	21.	23.44	62	190000	2.5	3.80	7.2
830407	20.0	160.	1500	0	7.8	13.0	24.0	14	2	22.	23.12	51	20000	1.0	-99.00	7.8
830421	14.0	58.	1400	3.30	7.7	8.0	8.7	10	10	17.	24.16	42	30000	2.0	7.00	8.0
830421	14.0	60.	1390	11.00	7.8	9.1	9.8	10	8	16.	23.11	44	60000	2.0	7.00	8.0
830505	12.0	57.	1850	0	8.4	9.5	9.9	10	10	16.	41.43	57	130000	13.0	13.40	7.7
830519	4.2	160.	1880	0	8.4	8.7	9.0	12	8	12.	42.34	54	10000	9.0	12.60	8.3
830602	1.8	190.	2120	.20	8.2	7.0	7.9	2	2	8.	26.77	60	80000	17.0	11.80	7.3
830616	2.5	75.	2270	3.50	8.0	9.6	10.0	0	0	8.	37.76	32	130000	20.0	8.40	7.6
830616	2.6	89.	2270	3.00	8.1	9.6	10.0	4	4	8.	37.23	29	140000	19.5	8.70	7.5
830630	1.0	73.	2130	2.70	8.0	9.6	10.0	12	12	7.	36.21	16	20000	21.0	5.70	8.1
830714	1.0	95.	2290	.90	7.7	5.6	8.6	4	4	5.	26.07	15	64000	24.0	4.00	8.1
830728	1.0	78.	2190	1.00	7.7	9.3	9.7	16	16	5.	25.95	10	109000	21.0	4.30	7.0

-99 REPRESENTS MISSING DATA

TABLE 27. WELL 1 WATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF #/100ML	TEMP C	DO MG/L	FIELD PH
810806	1.0	-99	2930	0.61	8.3	0.0	0.0	0.0	-99	-99	104000	16.0	2.0	-99
810903	4.0	-99	3710	0.11	8.7	0.0	4.0	17.0	11.1	-99	10000	17.0	6.0	7.2
811022	0.0	-99	3500	0.91	-99	0.0	19.0	17.0	3.0	-99	50000	10.0	9.2	7.8
811119	0.9	-99	4300	1.39	7.8	0.0	13.0	6.0	21.0	-99	10000	5.0	7.0	7.7
811217	-99	441.	4260	1.59	8.0	0.0	11.0	-99	-99	-99	10000	-99	-99	-99
820603	1.1	-99	4760	3.40	7.5	0.0	17.0	5.0	12.6	11.	1000	8.0	5.6	7.6
820701	1.0	-99	5450	1.90	7.8	0.0	1.0	10.0	10.0	-99	100	16.0	5.8	8.0
820805	1.0	-99	6090	1.80	7.6	1.0	8.0	4.0	9.9	-99	100	16.0	3.4	7.3
820916	1.0	-99	6140	6.00	7.6	0.0	3.0	3.0	9.5	-99	250	16.0	6.0	8.0
821014	1.0	-99	6710	0.40	7.8	0.0	43.0	3.0	20.8	-99	100	12.0	7.8	6.3
830324	1.0	-99	6600	5.30	7.5	0.0	4.0	4.0	19.8	-99	330	3.0	5.6	7.1
830505	1.2	-99	15000	4.00	7.5	0.0	9.0	4.0	40.9	-99	90	6.0	9.8	7.8
830728	1.0	-99	10420	4.70	7.5	1.0	4.0	3.0	47.2	-99	100	17.0	3.5	7.0

NOTE: -99 REPRESENTS MISSING DATA VALUES.

TABLE 28. WELL 2 WATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF #/100ML	TEMP C	DO MG/L	FIELD PH
820603	1.4	-99	1940	0.1	7.6	0.0	51.0	8.0	23.4	8.0	1000	9.0	6.2	7.7
830505	1.0	-99	9780	4.1	7.5	0.0	1.0	8.0	36.6	-99	80	7.5	9.7	7.8
830616	1.0	-99	4530	4.1	7.3	0.0	1.0	2.0	27.4	-99	60	14.0	3.6	7.2
830714	1.0	-99	9850	4.7	7.2	1.0	1.0	4.0	50.0	-99	10	19.0	5.4	8.2
830728	1.0	-99	8700	5.3	7.5	1.0	3.0	4.0	32.7	-99	10	17.0	2.8	7.0

NOTE: -99 REPRESENTS MISSING DATA VALUES.

TABLE 29. WELL 3 WATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF #/100ML	TEMP C	DO MG/L	FIELD PH
820603	0.1	-99	4250	0.6	7.6	0.0	13.0	3.0	12.5	18.	1000	10.0	5.8	7.6
820701	1.0	-99	4840	1.7	7.4	0.0	2.0	5.0	14.0	-99	100	14.0	4.8	7.5
820805	3.6	-99	7540	0.0	7.9	1.0	11.0	10.0	31.8	-99	100	21.0	5.0	8.1
830505	1.3	-99	19300	4.7	7.7	0.0	1.0	10.0	105.0	-99	30	6.0	10.1	7.6
830714	1.0	-99	8170	0.5	7.5	1.0	1.0	2.0	42.1	-99	10	16.0	5.9	8.2
830728	1.0	-99	5530	4.6	7.5	1.0	3.0	3.0	36.9	-99	10	16.0	2.3	7.1

NOTE: -99 REPRESENTS MISSING DATA VALUES.

TABLE 30. WELL 5 WATER CHARACTERISTICS

DATE	NH3 MG/L	COD MG/L	COND EC	NO3 MG/L	LAB PH	ORTHO PO4 MG/L	TOTAL PO4 MG/L	TKN MG/L	TOC MG/L	BOD MG/L	FECAL COLIF #/100ML	TEMP C	DO MG/L	FIELD PH
810806	1.0	-99	9040	0.1	8.1	0.0	0.0	13.0	-99	-99	26000	14.0	0.8	-99
810903	4.0	-99	8850	0.1	7.8	0.0	3.0	4.0	25.5	-99	1000	14.0	5.9	7.4
811022	2.7	-99	7910	0.1	-99	0.0	6.0	12.0	16.5	-99	24000000	9.0	9.0	7.7
811119	0.9	-99	7400	0.1	7.5	0.0	24.0	9.0	13.0	-99	10000	5.0	4.0	7.3
811217	1.2	48.	4520	0.6	6.9	0.0	4.0	7.0	-99	-99	130000	4.5	5.0	6.9
820114	0.0	-99	2640	0.0	7.7	0.0	4.0	3.0	-99	-99	3400000	3.0	-99	7.3
820211	1.0	-99	2150	0.0	8.3	0.0	0.0	6.0	11.5	-99	31000	1.0	7.8	-99
820506	7.6	-99	2620	0.1	7.2	0.0	3.0	9.0	24.5	-99	10000	5.0	5.5	7.6
820603	6.4	-99	4650	0.1	7.0	0.0	5.0	8.0	17.0	16.	1000	8.0	3.1	6.8
820701	3.7	-99	6720	0.0	7.2	0.0	5.0	9.0	23.0	-99	300	11.5	3.2	7.4
820805	1.0	-99	4790	1.2	7.3	1.0	1.0	-99	52.1	-99	120	16.0	2.0	7.9
820916	3.1	-99	5970	2.3	7.3	0.0	5.0	7.0	11.0	-99	240	15.0	3.5	7.6
821014	2.9	-99	5140	2.8	7.3	0.0	2.0	6.0	16.1	-99	20	11.0	5.2	6.5
821110	7.4	-99	3010	7.5	7.3	0.0	0.0	8.0	7.0	-99	450	8.0	4.4	-99
830224	2.8	210.	4130	2.7	7.5	1.0	2.0	4.0	17.1	-99	10000	6.0	8.3	6.6
830324	2.8	-99	5000	2.0	7.4	0.0	1.0	4.0	16.9	-99	200	3.0	5.1	7.0
830505	10.0	-99	3790	3.8	7.3	0.0	1.0	6.0	17.5	-99	100	5.0	7.7	8.0
830616	5.4	-99	3230	2.6	7.1	0.0	1.0	6.0	15.9	-99	10	11.0	3.6	7.2
830714	3.2	-99	5040	7.1	7.2	1.0	1.0	7.0	18.1	-99	160	13.0	3.4	8.1
830728	-99	-99	-99	-99	7.3	-99	-99	-99	-99	-99	21700	15.0	1.8	6.9

NOTE: -99 REPRESENTS MISSING DATA VALUES.

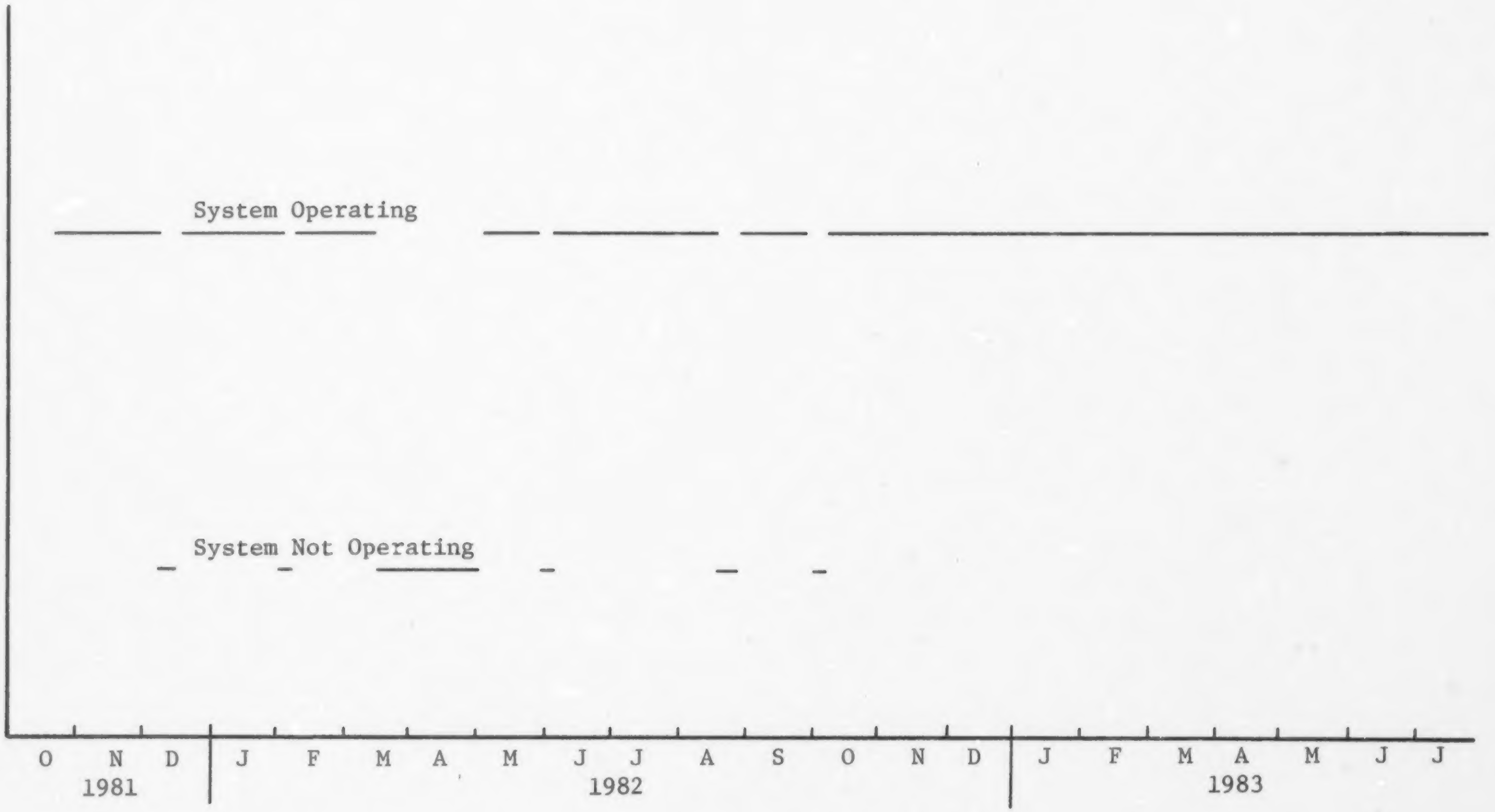

Figure 10. Operating history of system.

APPENDIX B

CLIMATOLOGICAL DATA

TABLE 31. DAILY PRECIPITATION AND AIR TEMPERATURE FROM TEST SITE

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
810701	3.54	16.5	810810	0.00	9.6	810919	0.00	16.0
810702	0.44	12.6	810811	0.00	13.3	810920	0.00	17.0
810703	0.21	13.6	810812	0.46	12.9	810921	0.00	14.7
810704	0.03	16.3	810813	0.06	14.6	810922	0.00	14.7
810705	0.00	20.0	810814	0.06	15.0	810923	0.00	12.6
810706	0.03	19.9	810815	0.00	14.5	810924	0.15	11.0
810707	0.00	21.0	810816	0.18	12.2	810925	0.13	8.5
810708	0.00	17.2	810817	0.06	14.3	810926	0.03	9.3
810709	0.23	1704	810818	0.00	14.6	810927	0.00	11.1
810710	0.00	20.1	810819	0.05	15.1	810928	0.03	11.1
810711	0.00	21.4	810820	0.08	12.6	810929	0.05	13.6
810712	0.74	17.2	810821	0.58	16.4	810930	0.00	6.3
810713	0.73	16.3	810822	0.00	13.9	811001	0.00	8.5
810714	0.00	18.8	810823	0.00	14.7	811002	0.00	10.7
810715	0.00	19.3	810824	0.08	10.0	811003	0.00	8.9
810716	0.00	20.6	810825	0.00	12.2	811004	0.10	7.2
810717	0.03	17.0	810826	0.00	14.3	810005	0.03	4.0
810718	0.03	16.4	810827	0.18	13.6	811006	0.00	7.4
810719	0.00	18.3	810828	0.00	12.2	811007	0.00	7.4
810720	0.03	20.7	810829	0.00	15.1	811008	0.00	6.8
810721	0.00	19.7	810830	0.05	16.8	811009	0.00	4.9
810722	0.00	18.2	810831	0.00	9.6	811010	0.00	8.9
810723	0.00	20.8	810901	0.00	14.3	811011	0.03	9.2
810724	0.36	17.4	810902	0.13	13.8	811012	0.15	4.6
810725	0.51	13.1	810903	0.15	12.0	811013	0.74	4.7
810726	1.50	10.0	810904	0.00	17.1	811014	0.30	3.2
810727	0.00	12.1	810905	0.00	15.7	811015	0.10	2.2
810728	0.00	16.8	810906	0.00	10.3	811016	0.86	-0.8
810729	0.00	20.6	810907	0.00	9.7	811017	0.10	-1.5
810730	0.00	17.1	810908	0.00	10.0	811018	0.00	1.4
810731	0.00	17.4	810909	0.00	13.2	811019	0.03	3.8
810801	0.00	18.6	810910	0.00	12.4	811020	0.00	5.6
810802	0.00	18.3	810911	0.00	11.4	811021	0.00	-4.0
810803	0.00	19.6	810912	0.00	14.3	811022	0.03	-4.7
810804	0.00	20.8	810913	0.00	12.9	811023	0.00	1.3
810805	0.00	18.3	810914	1.55	11.1	811024	0.53	-5.1
810806	0.00	17.1	810915	0.06	10.3	811025	0.03	-4.7
810807	0.00	14.5	810916	0.00	8.6	811026	0.03	5.8
810808	0.26	14.7	810917	0.00	9.3	811027	0.00	5.0
810809	1.32	9.3	810918	0.00	9.9	811028	0.00	6.8

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
811029	0.03	3.9	811208	0.00	2.2	820117	0.00	-0.8
811030	0.08	0.1	811209	0.00	1.9	820118	0.03	-4.0
811031	-99	-3.9	811210	0.03	5.8	820119	0.00	-7.8
811101	0.03	-1.4	811211	0.00	-0.1	820120	0.00	-9.0
811102	0.00	1.3	811212	0.00	-2.8	820121	0.00	-6.7
811103	0.00	-1.3	811213	0.00	-6.8	820122	0.13	-13.9
811104	0.00	-0.3	811214	0.00	-0.8	820123	0.00	-4.5
811105	0.00	-1.7	811215	0.10	-0.8	820124	0.00	-0.8
811106	0.00	1.5	811216	0.20	-8.6	820125	0.03	0.6
811107	0.00	1.8	811217	0.00	-18.3	820126	0.00	4.6
811108	0.00	-3.3	811218	0.00	-5.8	820127	0.05	-3.6
811109	0.00	-1.3	811219	0.00	1.9	820128	0.00	-4.6
811110	0.00	-0.3	811220	0.08	2.8	820129	0.00	-8.8
811111	0.00	-0.7	811221	0.38	-4.5	820130	0.00	-99
811112	0.00	5.0	811222	0.05	-14.6	820131	0.00	-99
811113	0.00	7.0	811223	0.00	-20.6	820201	0.15	-9.1
811114	0.18	5.7	811224	0.00	-11.8	820202	0.00	-13.1
811115	0.03	5.1	811225	0.08	-9.9	820203	0.05	-18.9
811116	0.03	8.2	811226	0.05	-10.8	820204	0.00	-30.0
811117	0.00	3.8	811227	0.33	-16.4	820205	-99	-99
811118	0.23	-2.8	811228	0.03	-15.6	820206	-99	-99
811119	0.00	-5.7	811229	0.00	-5.7	820207	-99	-99
811120	0.00	-0.4	811230	0.05	-3.2	820208	0.18	-27.5
811121	0.00	2.6	811231	0.00	-11.5	820209	0.00	-14.6
811122	0.03	1.4	820101	0.10	-7.0	820210	0.00	-11.3
811123	0.03	0.1	820102	0.05	-14.7	820211	0.00	-9.9
811124	0.00	4.3	820103	0.00	-15.3	820212	0.00	-2.1
811125	0.20	-6.5	820104	0.08	-7.9	820213	0.00	3.9
811126	0.08	-99	820105	0.00	-4.3	820214	0.00	4.2
811127	0.00	-99	820106	0.05	-18.9	820215	0.00	3.9
811128	0.00	-99	820107	0.00	-17.9	820216	0.00	3.8
811129	0.00	-99	820108	0.03	-7.4	820217	0.00	-1.9
811130	0.08	-99	820109	0.08	-5.1	820218	0.00	-2.9
811201	0.00	-5.2	820110	0.00	-10.4	820219	0.00	4.0
811202	0.00	-1.4	820111	0.13	-3.9	820220	0.00	4.5
811203	0.00	-4.0	820112	0.18	-16.7	820221	0.00	5.0
811204	0.00	0.4	820113	0.03	-11.7	820222	0.03	6.9
811205	0.00	3.9	820114	0.00	-6.1	820223	0.03	1.0
811206	0.00	5.3	820115	0.00	-11.3	820224	0.00	-6.0
811207	0.00	1.3	820116	0.00	-8.1	820225	0.00	-4.3

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
820226	0.00	-3.6	820407	0.00	-6.8	820517	0.05	6.3
820227	0.03	-1.0	820408	0.03	-99	820518	0.03	10.1
820228	0.05	0.7	820409	0.00	-99	820519	0.03	7.4
820301	0.00	3.8	820410	0.00	-99	820520	0.05	4.9
820302	0.00	-0.7	820411	0.00	-99	820521	0.00	7.1
820303	0.00	-2.6	820412	0.25	1.9	820522	0.00	11.7
820304	0.13	-7.6	820413	0.00	6.4	820523	0.00	12.2
820305	0.03	-12.4	820414	0.00	5.3	820524	0.66	3.2
820306	0.00	-7.6	820415	0.00	2.1	820525	0.46	2.4
820307	0.00	-7.8	820416	0.00	-4.3	820526	0.00	10.0
820308	0.00	-0.1	820417	0.00	-99	820527	0.03	14.0
820309	0.00	1.3	820418	0.00	-99	820528	0.03	8.9
820310	0.00	3.2	820419	0.18	-99	820529	0.00	8.6
820311	0.00	2.8	820420	0.05	-99	820530	0.20	4.5
820312	0.00	-5.1	820421	0.00	-99	820531	0.00	8.5
820313	0.03	0.4	820422	0.00	-99	820601	0.66	7.1
820314	0.00	-0.1	820423	0.00	-99	820602	0.05	6.1
820315	0.00	-0.3	820424	0.00	-99	820603	0.00	7.2
820316	0.00	0.0	820425	0.00	-99	820604	0.00	10.3
820317	0.51	-2.6	820426	0.51	-99	820605	0.00	10.3
820318	0.00	-0.6	820427	0.53	-99	820606	0.03	6.7
820319	0.10	-4.9	820428	0.00	-99	820607	0.10	9.5
820320	0.00	-9.7	820429	0.00	3.2	820608	0.00	6.7
820321	0.00	-9.2	820430	0.00	5.0	820609	0.10	7.0
820322	0.05	-5.6	820501	0.00	7.4	820610	0.03	12.0
820323	0.00	-2.4	820502	0.00	8.9	820611	0.03	11.0
820324	0.23	-7.2	820503	0.13	9.9	820612	0.00	9.4
820325	0.00	-99	820504	0.00	7.2	820613	0.00	14.0
820326	0.00	-99	820505	0.00	-0.3	820614	0.03	9.6
820327	0.00	-99	820506	0.00	-0.1	820615	0.20	7.6
820328	0.00	-99	820507	0.00	5.4	820616	0.53	10.7
820329	0.05	-99	820508	0.08	7.2	820617	0.00	9.3
820330	0.08	-99	820509	0.00	9.6	820618	0.03	7.2
820331	0.00	-99	820510	0.08	5.6	820619	0.05	10.8
820401	0.00	7.6	820511	0.25	2.8	820620	0.00	13.5
820402	0.00	-3.8	820512	0.81	2.6	820621	0.00	13.6
820403	0.00	1.5	820513	1.22	-0.3	820622	0.10	14.3
820404	0.08	0.0	820514	0.51	0.8	820623	0.00	14.6
820405	0.05	-6.5	820515	0.00	3.8	820624	1.91	13.8
820406	0.00	-2.0	820516	0.05	5.1	820625	0.53	10.1

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
820626	0.00	12.2	820805	0.00	19.3	820914	0.94	2.1
820627	0.00	16.1	820806	0.00	19.6	820915	0.25	6.0
820628	0.00	19.9	820807	0.00	17.8	820916	0.00	12.8
820629	0.00	17.9	820808	0.00	17.8	820917	0.33	5.6
820630	0.00	16.7	820809	0.00	17.2	820918	0.03	11.8
820701	0.00	13.3	820810	0.25	15.6	820919	0.03	8.1
820702	0.00	-99	820811	0.00	17.3	820920	0.00	7.8
820703	0.00	-99	820812	0.00	19.0	820921	0.00	9.9
820704	0.00	-99	820813	0.00	15.3	820922	0.00	12.9
820705	0.10	15.9	820814	0.00	17.5	820923	0.00	13.1
820706	0.00	12.1	820815	0.00	19.5	820924	0.00	12.4
820707	0.00	15.8	820816	2.16	15.8	820925	0.00	12.4
820708	0.00	17.0	820817	0.10	20.0	820926	0.00	14.6
820709	0.05	14.7	820818	0.00	19.7	820927	0.76	8.6
820710	0.00	14.2	820819	0.03	19.3	820928	0.05	7.9
820711	0.00	15.7	820820	1.65	17.8	820929	0.03	4.0
820712	0.08	17.8	820821	0.03	20.0	820930	0.00	-0.1
820713	0.08	17.0	820822	0.08	20.0	821001	0.00	5.3
820714	0.00	20.0	820823	0.03	19.2	821002	0.00	6.3
820715	0.00	17.8	820824	0.00	15.1	821003	0.00	7.9
820716	0.00	18.5	820825	0.00	14.9	821004	0.00	8.6
820717	0.00	18.1	820826	0.13	16.3	821005	0.00	0.3
820718	0.00	18.5	820827	0.05	16.0	821006	0.00	4.9
820719	0.00	17.5	820828	0.05	16.5	821007	0.00	10.4
820720	0.00	17.6	820829	0.13	16.5	821008	0.43	-2.0
820721	0.00	21.0	820830	0.00	17.4	821009	0.13	-4.0
820722	0.00	22.8	820831	0.00	16.8	821010	0.00	-5.7
820723	0.10	22.9	820901	0.03	11.7	821011	0.00	-0.8
820724	0.00	19.2	820902	0.00	14.7	821012	0.18	2.2
820725	0.03	19.0	820903	0.00	14.7	821013	0.08	1.0
820726	2.44	17.2	820904	0.00	16.3	821014	0.00	8.5
820727	0.38	13.8	820905	0.00	14.7	821015	0.00	6.4
820728	0.71	14.2	820906	0.00	13.3	821016	0.00	7.9
820729	0.10	11.8	820907	0.00	13.5	821017	0.00	7.6
820730	0.03	14.4	820908	0.00	11.7	821018	0.46	4.6
820731	0.00	17.1	820909	0.00	14.5	821019	0.41	-9.7
820801	0.00	21.0	820910	0.00	13.6	821020	0.00	-5.3
820802	0.13	18.1	820911	1.02	4.5	821021	0.00	5.7
820803	0.00	16.8	820912	0.03	6.0	821022	0.00	7.2
820804	0.86	16.0	820913	1.37	4.3	821023	0.00	7.0

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
821024	0.00	9.3	821203	0.00	-9.2	830112	0.00	-2.9
821025	0.00	8.2	821204	0.18	-5.3	830113	0.00	-1.7
821026	0.00	8.1	821205	0.00	-7.6	830114	0.00	-7.4
821027	0.00	0.3	821206	0.13	-3.8	830115	0.00	-8.5
821028	0.00	-0.8	821207	0.00	-13.2	830116	0.00	-8.2
821029	0.00	2.6	821208	0.00	-15.8	830117	0.00	-6.3
821030	0.00	-99	821209	0.00	-3.3	830118	0.00	-5.8
821031	0.05	-99	821210	0.00	-7.5	830119	0.00	-6.4
821101	0.08	-0.3	821211	0.00	-11.0	830120	0.00	-5.9
821102	0.56	-9.0	821212	0.00	-1.9	830121	0.00	-6.0
821103	0.00	-7.9	821213	0.00	-3.1	830122	0.00	-5.3
821104	0.00	-1.5	821214	0.00	-9.9	830123	0.00	-4.7
821105	0.00	3.8	821215	0.00	-4.2	830124	0.00	-3.5
821106	0.00	7.0	821216	0.00	2.2	830125	0.05	-5.8
821107	0.00	2.6	821217	0.00	-1.1	830126	0.00	-3.9
821108	0.00	1.9	821218	0.00	-8.1	830127	0.00	2.4
821109	0.00	-1.5	821219	0.00	-3.5	830128	0.23	-5.0
821110	0.00	1.5	821220	0.00	-2.4	830129	0.03	-8.5
821111	0.91	-4.6	821221	0.00	2.4	830130	0.00	-9.6
821112	0.18	-12.2	821222	0.00	-0.1	830131	0.00	-7.6
821113	0.00	-99	821223	0.53	-0.9	830201	0.00	-8.8
821114	0.00	-99	821224	1.07	-99	830202	0.03	-12.5
821115	0.00	-6.1	821225	0.00	-99	830203	0.00	-16.0
821116	0.00	-3.1	821226	0.00	-99	830204	0.00	-15.8
821117	0.00	-1.7	821227	0.15	-99	830205	0.00	-13.9
821118	0.00	1.7	821228	0.03	-99	830206	0.00	-9.5
821119	0.00	-0.6	821229	0.00	-99	830207	0.00	-6.5
821120	0.00	-6.5	821230	0.00	-99	830208	0.00	-4.3
821121	0.00	-6.1	821231	0.00	-99	830209	0.00	-2.8
821122	0.33	-13.5	830101	0.00	-99	830210	0.00	-5.1
821123	0.00	-99	830102	0.00	-99	830211	0.00	-6.4
821124	0.00	-99	830103	0.00	-99	830212	0.00	-0.8
821125	0.00	-99	830104	0.00	-99	830213	0.00	0.6
821126	0.00	-99	830105	0.00	-99	830214	0.10	-5.0
821127	0.00	-99	830106	0.00	-99	830215	0.00	-6.8
821128	0.00	-99	830107	0.00	-99	830216	0.00	-1.7
821129	0.00	-99	830108	0.00	-99	830217	0.00	-1.7
821130	0.00	1.7	830109	0.00	-99	830218	0.00	1.8
821201	1.07	-3.8	830110	0.00	-99	830219	0.05	-5.0
821202	0.15	-7.9	830111	0.00	-0.6	830220	0.00	-7.4

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
830221	0.00	-4.7	830402	0.00	-3.6	830512	0.28	1.3
830222	0.00	-3.8	830403	0.28	-9.6	830513	0.00	-2.4
830223	0.00	-3.9	830404	0.23	-11.0	830514	0.00	-1.0
830224	0.00	-3.3	830405	0.00	-12.4	830515	0.00	2.4
830225	0.00	-0.1	830406	0.00	-16.3	830516	0.13	2.2
830226	0.00	-1.0	830407	0.03	-11.4	830517	0.58	-1.1
830227	0.00	-1.4	830408	0.03	-8.6	830518	0.03	2.5
830228	0.00	-0.6	830409	0.00	-2.4	830519	0.41	2.1
830301	0.00	2.2	830410	0.00	1.1	830520	0.00	3.2
830302	0.00	0.6	830411	0.08	-1.3	830521	0.20	7.4
830303	0.00	0.3	830412	1.32	-7.5	830522	0.00	6.1
830304	0.61	-2.1	830413	0.56	-12.5	830523	0.00	9.0
830305	0.81	-3.6	830414	0.00	-14.3	830524	0.00	11.4
830306	0.86	-4.4	830415	0.00	-8.5	830525	0.00	13.1
830307	0.00	-3.9	830416	0.03	-2.9	830526	0.00	12.5
830308	0.05	-5.6	830417	0.03	-0.4	830527	0.00	13.6
830309	0.00	-4.5	830418	0.03	2.8	830528	0.00	12.4
830310	0.00	-0.4	830419	0.00	2.4	830529	0.05	10.3
830311	0.00	0.3	830420	0.05	3.1	830530	0.25	3.2
830312	0.00	2.0	830421	4.80	-1.0	830531	0.20	3.8
830313	0.00	3.8	830422	1.30	-2.6	830601	0.13	6.3
830314	0.23	-0.1	830423	0.05	0.6	830602	0.13	7.2
830315	0.69	-5.0	830424	0.03	2.9	830603	0.33	9.9
830316	0.08	-7.2	830425	0.03	4.3	830604	2.31	8.1
830317	0.00	-8.6	830426	0.00	1.5	830605	0.23	5.4
830318	0.08	-8.5	830427	0.00	2.9	830606	0.23	4.9
830319	0.00	-11.3	830428	0.00	2.2	830607	0.36	8.9
830320	0.00	-10.6	830429	0.03	3.3	830608	0.00	10.8
830321	0.00	-7.2	830430	0.13	2.6	830609	0.03	11.3
830322	0.00	-6.3	830501	0.23	-0.4	830610	0.00	12.6
830323	0.05	-2.8	830502	0.23	0.0	830611	0.18	14.4
830324	0.05	-3.5	830503	0.00	1.1	830612	0.03	6.9
830325	1.17	-6.7	830504	0.00	3.2	830613	0.15	4.4
830326	0.05	-9.7	830505	0.00	4.5	830614	0.00	8.3
830327	0.00	-6.7	830506	0.00	1.5	830615	0.00	11.3
830328	0.00	-3.9	830507	0.05	5.4	830616	0.00	12.0
830329	0.00	-4.0	830508	0.00	6.7	830617	0.00	12.6
830330	0.00	1.5	830509	0.00	7.6	830618	0.03	15.4
830331	0.23	-3.9	830510	0.00	5.7	830619	0.00	15.0
830401	0.00	-4.6	830511	0.05	-2.2	830620	0.03	14.9

TABLE 31. (continued)

DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C	DATE	PREC cm	TEMP °C
830621	0.00	15.6	830731	0.03	16.8			
830622	0.00	14.2						
830623	0.00	16.0						
830624	0.00	15.0						
830625	0.03	16.9						
830626	0.10	10.1						
830627	0.66	7.9						
830628	0.00	11.5						
830629	0.00	14.9						
830630	0.03	14.0						
830701	0.00	15.3						
830702	0.00	13.1						
830703	0.48	11.7						
830704	0.00	12.6						
830705	0.05	16.5						
830706	0.00	17.1						
830707	0.00	18.6						
830708	0.10	18.1						
830709	1.52	17.2						
830710	0.00	14.0						
830711	0.00	13.3						
830712	0.00	15.6						
830713	0.00	17.9						
830714	0.00	16.4						
830715	0.05	12.2						
830716	0.03	14.7						
830717	0.00	17.1						
830718	0.00	17.8						
830719	0.23	18.2						
830720	1.68	17.8						
830721	0.00	15.4						
830722	0.00	15.6						
830723	0.03	14.5						
830724	0.03	16.5						
830725	0.10	17.0						
830726	0.00	14.4						
830727	0.00	14.0						
830728	0.00	16.5						
830729	0.00	17.5						
830730	0.00	16.3						

NOTE: -99 represents missing data values.

APPENDIX C

SURGE FLOW DATA

SURGE FLOW

The water delivery system for the overland flow wastewater plots using gated pipe operated reasonably well on the primary plots throughout the entire time of the experiment. However, a series of problems occurred on the raw wastewater plots. The sliding gates of the influent gated pipe to the raw wastewater plots became plugged almost immediately after installation. The extremely low flow rates required on the plots meant that the slide gates, on the gated pipe, were only partially open (approximately one-tenth of the workable slot opening). These low flow requirements resulted in a narrow vertical slit opening on the slide gate area. Since raw wastewater was being pumped to the area, the larger particles and hair being pushed through the line would plug of the slide gate opening, often within a 10-30 minute period.

A first attempt at solving this problem was to emit the entire flow to the plot from a single slide gate. This allowed for a wider slide gate opening (approximately ¼ of the workable slot opening). However, even with this width of slide gate opening, the raw influent would sometimes partially to completely plug the slide gate opening within the 8 hour operational period.

This plugging problem caused the raw portion of the water delivery system to be labor intensive and inefficient in controlling the amount of wastewater being applied to the two raw wastewater plots. A number of different operational schemes were tried in an effort to create a more efficient and reliable operating system. Of these, the only one which caused little to no plugging of the slide gates was one operated with a much enlarged slide gate opening. This allowed the larger solids and hair to pass without plugging the slide gate. This system caused a higher raw wastewater loading rate than desired for efficient treatment. This led to an analysis of other methods of control of the discharge for the raw wastewater plots.

Increasing the flow rate, yet maintaining the correct amount of raw wastewater to the plots by pulsating or surging the flow in a cycle of on-off times, was thus envisioned as a method of control. The question then became one of how the water would travel in a series of surges down the plot and how surging the flow could be designed to maintain suitable treatment. Would the grass surface damp out the series of surge waves to a continuous flow runoff pattern at some distance down the plot length? If the surging of the flow could be damped out to simulate continuous flow, then the rest of the plot should see little change, and treatment of approximately the same quality would be retained on the lower sections of the plots. This method of applying water in an intermittent or pulsating fashion according to a specified cycle of on and off times was termed surge flow. A study of surge flow was thus included in the project so that a satisfactory technique for applying low volumes of raw wastewater over time to an overland flow system could be designed and maintained.

Study Objectives

Before surge flow can be put into use on an overland flow water treatment system, an optimum or acceptable cycle of on and off times must be chosen. To find this parameter, the following questions must be answered:

1. What is the optimum cycle ratio to keep the instantaneous flow rate as high as possible while simultaneously damping the surges in the shortest possible plot length?

2. What is the effect of using different on and off times in the same cycle ratio?

3. What relationships are present between the cycle time, loading rate and damping length in attenuating surge flow runoff patterns?

This study of surge flow addressed all of the above questions in order to produce criteria necessary to design a surge flow overland treatment system. In this study the quality of water treatment caused by using a surge flow application technique was not addressed.

Literature

A variety of water delivery systems has been used in the past to apply wastewater to the land in order to treat the wastewater. These methods include spray irrigation using an assortment of nozzles and surface irrigation methods ranging from flood irrigation to troughs with trickling orifices. These water delivery methods all required at least primary water treatment with many using secondary effluent from a water treatment facility (Carlson, 1974; Middlebrooks, 1979; Reynolds, 1980; Tucker, 1980; Leland, 1975; Slelton, 1978; Haith, 1977; and Boyt, 1977). Martel, 1980 showed that overland flow wastewater treatment can be effective on raw wastewater without pretreatment. However, the hydraulic system required to deliver raw wastewater at the low loading rates required for good treatment can be a problem as indicated above.

Our literature search did not uncover any research on surge flow in relation to wastewater. However, Bishop (1980) used surge flow techniques on furrow irrigation to try and increase the efficiency of water use by decreasing the deep percolation losses near the top of the flow system. The significant conclusions that resulted from this study were that surge flow irrigation would provide a substantial decrease in the volume of water needed because high infiltration losses at the top of the furrows, associated with continuous water application, were reduced with surge flow, and that advance time down the furrows was shortest for a time cycle ratio of 1/3 on to 2/3 off compared with 1/2 on to 1/2 off and 2/3 on to 1/3 off for the same time increment. The results of this study were used in selecting cycle ratios for our study.

Model Testing

To determine the characteristics of an overland surge flow treatment system, a model of the Laramie overland flow plot 1 was constructed in the hydraulics laboratory at the University of Wyoming.

During the conception of the model design, the importance of both the Froude and Reynolds numbers was noted. However, a model based on both numbers was unfeasible due to space restrictions in the laboratory and the requirement that the model and prototype would have to be the same size if both Froude and Reynolds numbers were used. Thus, we tried to select an artificial turf for the model which would simulate quite closely the viscous forces in the prototype, leaving gravity as the most predominate force to be considered in the design. Based on this idea, the Froude number was used as the modeling criteria. This leads to the following modeling equation.

$$Qm^2 = Qp^2 \left(\frac{Wm}{Wp}\right)^5 \quad \text{.....................................} \quad (2)$$

where Qm = flow rate of model,

Qp = flow rate of prototype

Wm = width of the model, and

Wp = width of the prototype.

This equation was used to determine the test loading rate to be applied to the model. This calculation was made by inserting the prototype flow rate into the above equation once the model width was fixed. The presumption was that this procedure would be conducive to a comparison of model and prototype data.

Figure 11 shows a schematic of the test model and its dimensions. In an effort to simulate the prototype plot grasses, the flat bottom surface was covered with an artificial turf. The turf was installed in 1.22 m sections down the model to give five test lengths of 1.22, 2.44, 3.66, 4.88, and 6.10 m. These corresponded to 8.53, 17.07, 25.60, 34.14, and 42.67 m in the prototype. A series of tests were conducted at each of the 1.22 m sections before 1.22 more meters were added and the tests repeated. Each time the plywood dam (Figure 11) was placed below the appropriate section to collect the runoff through the effluent parts. This was done in an effort to see how damping of the surges was occurring with distance in the model. These data could then be compared with the actual field situation.

So that a variety of test loading rates were available for testing, five interchangeable tee sections containing circular ports were made that could be attached to the model influent section. The smallest test loading rate was calculated using the modeling equation (Equation (2)) and the actual prototype flow rate. Solving Equation (2) a flow rate of 0.223 l/min was calculated. Since this would be the model loading rate required at a continuous flow rate, an adjustment was necessary to allow for surge flow at a particular time cycle ratio. The time cycle ratio of 2/3 on to 1/3 off was selected as the base after studying the work done by Bishop (1980) on surge flow irrigation. In Bishop's studies, as indicated earlier, it was shown that the 2/3 on to 1/3 off time cycle ratio would be the best choice to simulate continuous flow, with respect to the water advance characteristics down an irrigated furrow. After adjustment, an instantaneous flow rate of 0.329 l/min was computed for the 2/3 on to 1/3 off cycle time. By using this value in the Bernoulli and continuity equations, the orifice diameter needed to apply this loading on the plot was calculated. In addition to this orifice size, four larger sizes were drilled into the remaining five individual tee sections to give instantaneous test flow rates of 0.329, 0.397, 0.587, 0.761, and 0.893 l/min in the model.

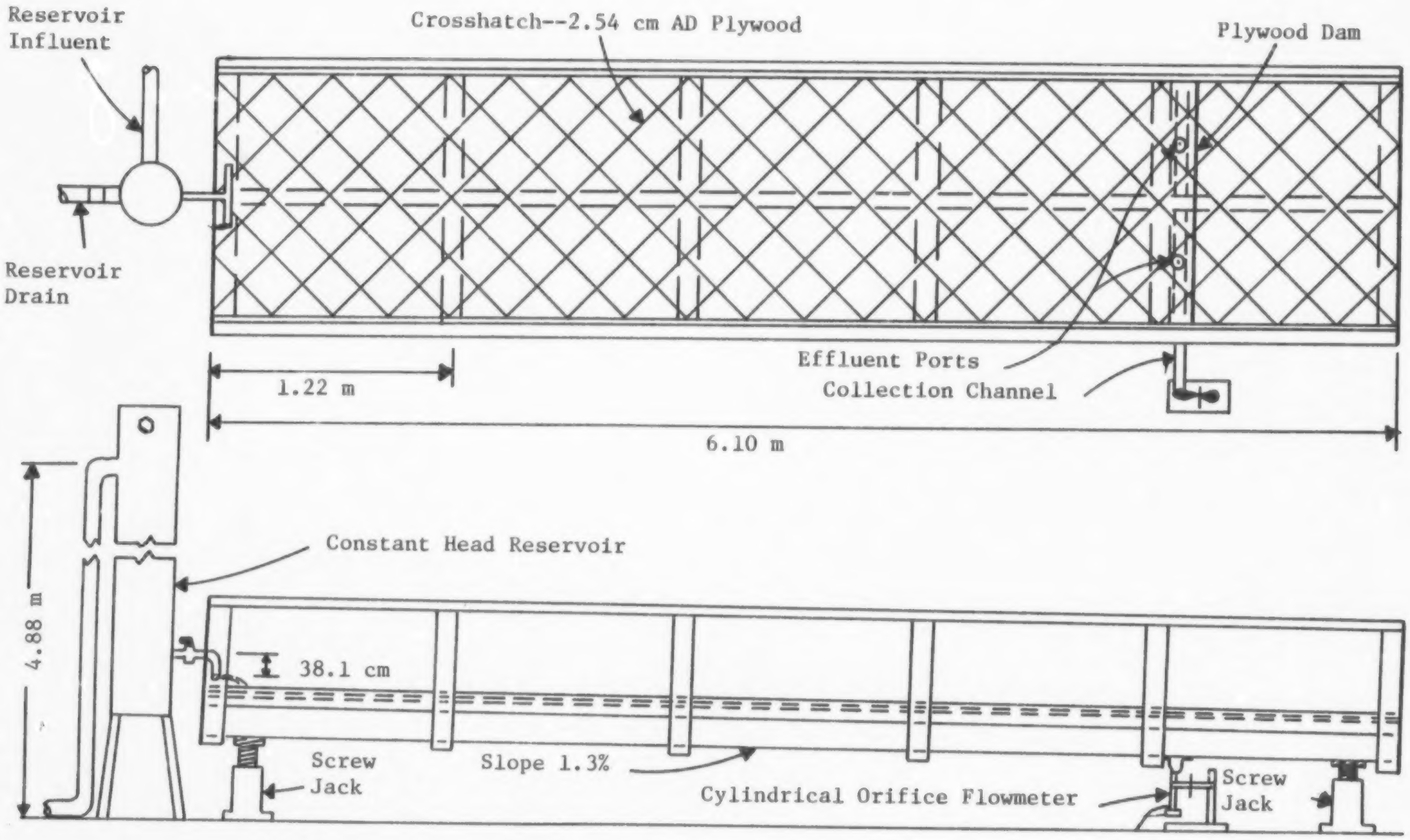
Reservoir Influent
Crosshatch--2.54 cm AD Plywood
Plywood Dam
Reservoir Drain
Effluent Ports
Collection Channel
1.22 m
6.10 m
Constant Head Reservoir
4.88 m
38.1 cm
Screw Jack
Slope 1.3%
Cylindrical Orifice Flowmeter
Screw Jack

Figure 11. Schematic of test model.

This corresponded to 42.78, 51.48, 76.09, 98.80, and 115.83 l/min in the prototype. The five flow rates were used for all cycle times tested.

Holes were drilled and a plywood dam installed at the bottom of each test section. Figure 11 shows this. A drain system was devised to collect the runoff and measure it and an orifice system was used to measure flow rate off the test section.

Testing the model consisted of surging the influent flow at a particular cycle time while simultaneously recording the runoff at the bottom of the test section. As implied previously, the majority of the model testing was done using the 2/3 on to 1/3 off time cycle ratio. Experiments were run at cycle times of (minutes on:minutes off) 2:1, 4:2, and 10:5 with at least three influent flow rates being tested at each of five model lengths. (A cycle time of 2:1 indicates a cycle of 2 minutes on to 1 minute off. In addition to these tests, the time cycle ratio of 1/2 on to 1/2 off was also tested at cycle times of 2:2, 4:4, and 10:10 with an influent flow rate of 0.587 l/min, at model lengths of 2.44, 3.66, 4.88, and 6.10 m. These tests were run to be sure that, as was indicated by Bishop's (1980) data, the 2/3 on to 1/3 off cycle ratio did the best job of simulating continuous flow .

Model Data Analysis

The model test data of instantaneous runoff versus time were plotted to give hydrographs. Figure 12 shows these. These hydrographs show the peak and valley flow pattern that is expected with surge flow application. The variable that is of most interest in the search for a cycle time, loading rate, and damping length that will match a continuous runoff pattern is the average range value between the peaks and valleys of the hydrograph. This average range value was determined by taking the average peak value and subtracting the average valley value of the cyclic data. An average range value of zero indicates that the test parameters of cycle time, loading rate, and damping length were combined in the correct fashion to simulate a continuous flow pattern. Even though all three of the model's parameters were interrelated in the production of the average range value, an attempt was made to define the relationship between the average range and each parameter individually.

The first parameter set studied was the relationship between damping length and average range. The hydrographs were used to develop Figure 12 from Table 32. The parameters of cycle time and applied flow rate were held constant to make it possible to compare average range values for increasing test lengths. Figure 13 shows the relationship between average range and model length. As was expected, the average range value tended to drop as the damping length was increased. More important, however, was the observation that the most rapid decrease in the average range value occurred between the 1.22 and 2.44 m model length for the 2/3 on to 1/3 off time cycle ratio. Model lengths larger than 2.44 m showed in only slight average range value drops by comparison. If this fact holds true in the prototype testing, using surge flow at a 2/3 on to 1/3 off time cycle ratio could be the key to a feasible tool for controlling influent plugging.

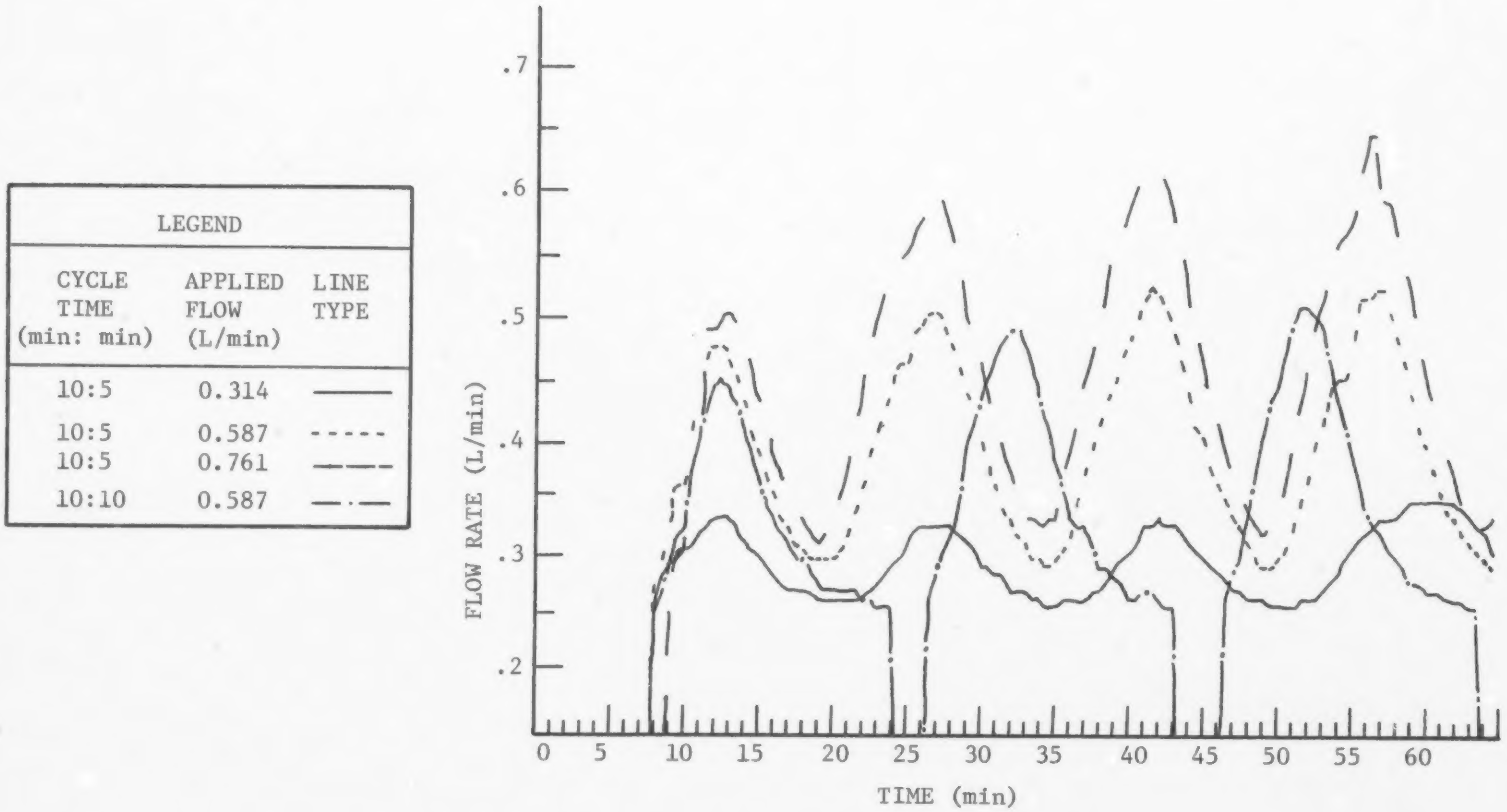

Figure 12. Model runoff hydrograph (4.9 m).

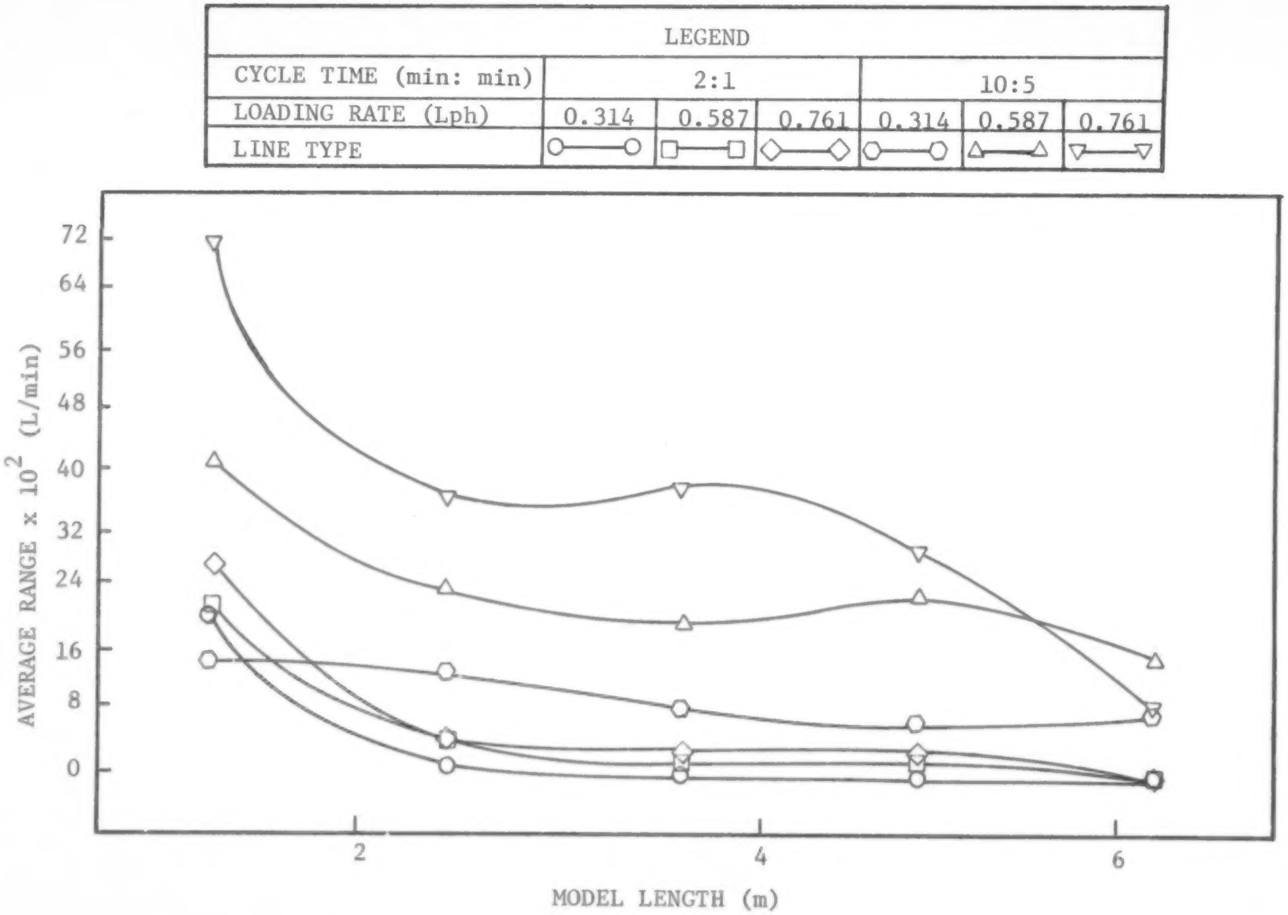

Figure 13. Model data: model length vs average range.

TABLE 32. MODEL DATA: MODEL LENGTH VS AVERAGE RANGE

CYCLE TIME ON:OFF (min:min)	APPLIED FLOW RATE (l/min)	MODEL LENGTH (m)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
2:1	0.314	1.2	0.360	0.151	0.208
		2.4	0.212	0.204	0.008
		3.7	0.220	0.220	0.000
		4.9	0.288	0.228	0.000
		6.1	0.212	0.212	0.000
	0.397	1.2	0.379	0.208	0.170
		2.4	0.257	0.235	0.023
	0.587	1.2	0.503	0.284	0.220
		2.4	0.379	0.333	0.045
		3.7	0.371	0.356	0.015
		4.9	0.386	0.371	0.015
		6.1	0.326	0.326	0.000
	0.761	1.2	0.750	0.473	0.276
		2.4	0.507	0.462	0.045
		3.7	0.519	0.492	0.026
		4.9	0.485	0.454	0.030
		6.1	0.454	0.454	0.000
	0.893	1.2	0.772	0.318	0.454
		2.4	0.507	0.462	0.045
4:2	0.314	1.2	0.367	0.151	0.216
		2.4	0.265	0.197	0.072
		3.7	0.220	0.204	0.015
		4.9	0.220	0.204	0.015
		6.1	0.227	0.212	0.015
	0.397	1.2	0.420	0.151	0.269
		2.4	0.288	0.220	0.068

TABLE 32. (continued)

CYCLE TIME ON:OFF (min:min)	APPLIED FLOW RATE (1/min)	MODEL LENGTH (m)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
4:2	0.587	1.2	0.560	0.223	0.337
		2.4	0.401	0.288	0.114
		3.7	0.394	0.333	0.061
		4.9	0.310	0.254	0.057
		6.1	0.371	0.348	0.023
	0.761	1.2	0.632	0.235	0.397
		2.4	0.541	0.424	0.117
		3.7	0.538	0.447	0.091
		4.9	0.556	0.454	0.102
		6.1	0.439	0.439	0.000
	0.893	1.2	0.814	0.235	0.579
		2.4	0.572	0.432	0.140
10:5	0.314	1.2	0.303	0.151	0.151
		2.4	0.288	0.151	0.136
		3.7	0.273	0.182	0.091
		4.9	0.329	0.257	0.072
		6.1	0.261	0.182	0.079
	0.397	1.2	0.424	0.151	0.273
		2.4	0.341	0.182	0.159
	0.587	1.2	0.560	0.151	0.409
		2.4	0.530	0.284	0.246
		3.7	0.500	0.299	0.201
		4.9	0.522	0.288	0.235
		6.1	0.443	0.288	0.155

TABLE 32. (continued)

CYCLE TIME ON:OFF (min:min)	APPLIED FLOW RATE (l/min)	MODEL LENGTH (m)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
10:5	0.761	1.2	0.848	0.151	0.697
		2.4	0.689	0.322	0.367
		3.7	0.697	0.318	0.379
		4.9	0.628	0.333	0.295
		6.1	0.500	0.413	0.087
	0.893	1.2	0.886	0.151	0.734
		2.4	0.689	0.288	0.401
20:10	0.893	1.2	0.871	0.151	0.719
2:2	0.397	2.4	0.212	0.204	0.008
	0.587	3.7	0.326	0.318	0.008
		4.9	0.280	0.257	0.023
		6.1	0.257	0.238	0.019
4:4	0.397	2.4	0.288	0.182	0.110
	0.587	3.7	0.363	0.295	0.068
		4.9	0.326	0.223	0.102
		6.1	0.295	0.220	0.076
10:10	0.397	2.4	0.386	0.151	0.235
	0.587	3.7	0.526	0.288	0.273
		4.9	0.492	0.257	0.235
		6.1	0.424	0.182	0.242

A similar process was used on the same data to analyze the relationship between the average range and application rate. Figure 14 depicts graphically the data in Table 33. Figure 14 shows the trend for the average range value to increase as loading rates are increased.

The last parameter analyzed was the cycle time and its effect on average range. Figure 15 was constructed from the data in Table 34. Figure 15 shows longer cycle times create larger values of average range. This was true for the time cycle ratio 1/2 on and 1/2 off also.

The data in Figure 15, along with other data tabulated in Tables 32 and 35 for different cycle times show that on the average longer off times to on times leads to larger average range values of flow rate down the plot. The time cycle ratio of 2/3 on to 1/3 off should, therefore, do a reasonable job of simulating a continuous flow pattern than longer off times.

It must be understood that the magnitude of average range values inherent to the runoff hydrograph is dictated by the combination of damping length, application rate and cycle time employed in the operation of the system. When using a surge flow system, these three parameters should be selected together because their effect on average range occurs simultaneously.

There were only a couple of other test results worth mentioning. On the average, the time for a cycle to reiterate was equal to the summation of on and off time. Also, the lag time increased as the damping length increased, and decreased as the loading rate increased. No trend could be determined between lag time and cycle time.

The results of the model data indicated:

1. The time cycle ratio of 2/3 to 1/3 off appears to lead to a runoff flow pattern that is the closest to a continuous flow pattern, when compared to cycle ratios of shorter on time.

2. Average range is a function of damping length, loading rate and cycle time. The parameter characteristics are:

    a. Increased damping lengths decrease the average range in the runoff hydrograph.

    b. Decreased loading rates decrease the range in runoff hydrograph.

    c. Shorter cycle times create smaller average range values in the runoff hydrograph.

Field Testing (Prototype)

Surge flow testing was also performed on plot 1 of the overland flow treatment system (Figure 1). Information gained from the model tests was used in determining what tests to run on the actual overland flow plot.

The influent flow to this plot was applied through one slide gate in the gated pipe at the top of the plot. This gate is referred to as the sliding

TABLE 33. MODEL DATA: FLOW RATE VS AVERAGE RANGE

CYCLE TIME ON:OFF (min:min)	MODELED LENGTH (m)	APPLIED FLOW RATE (l/min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
2:1	1.2	0.314	0.360	0.151	0.208
		0.397	0.379	0.208	0.170
		0.587	0.503	0.284	0.220
		0.761	0.750	0.473	0.276
		0.893	0.772	0.318	0.454
	2.4	0.314	0.212	0.204	0.015
		0.397	0.257	0.235	0.023
		0.587	0.379	0.333	0.045
		0.761	0.462	0.507	0.045
		0.893	0.507	0.462	0.045
	3.7	0.314	0.220	0.220	0.000
		0.587	0.371	0.356	0.015
		0.761	0.519	0.492	0.026
	4.9	0.314	0.288	0.288	0.000
		0.587	0.386	0.371	0.015
		0.761	0.485	0.454	0.030
	6.1	0.314	0.212	0.212	0.000
		0.587	0.326	0.326	0.000
		0.761	0.454	0.454	0.000
4:2	1.2	0.314	0.367	0.151	0.216
		0.397	0.420	0.151	0.269
		0.587	0.560	0.223	0.337
		0.761	0.632	0.235	0.397
		0.893	0.814	0.235	0.579

TABLE 33. (continued)

CYCLE TIME ON:OFF (min:min)	MODELED LENGTH (m)	APPLIED FLOW RATE (1/min)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
4:2	2.4	0.314	0.265	0.197	0.072
		0.397	0.288	0.216	0.068
		0.587	0.401	0.288	0.114
		0.761	0.541	0.424	0.117
		0.893	0.572	0.432	0.140
	3.7	0.314	0.216	0.204	0.015
		0.587	0.394	0.333	0.061
		0.761	0.538	0.447	0.091
	4.9	0.314	0.216	0.204	0.015
		0.587	0.310	0.254	0.057
		0.761	0.556	0.454	0.102
	6.1	0.314	0.227	0.212	0.015
		0.587	0.371	0.348	0.023
		0.761	0.439	0.439	0.000
10:5	1.2	0.314	0.303	0.151	0.151
		0.397	0.424	0.151	0.273
		0.587	0.560	0.151	0.409
		0.761	0.848	0.151	0.697
		0.893	0.886	0.151	0.734
	2.4	0.314	0.288	0.151	0.136
		0.397	0.341	0.182	0.159
		0.587	0.530	0.284	0.246
		0.761	0.689	0.322	0.367
		0.893	0.689	0.288	0.401

TABLE 33. (continued)

CYCLE TIME ON:OFF (min:min)	MODELED LENGTH (m)	APPLIED FLOW RATE (l/min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
10:5	3.7	0.314	0.273	0.182	0.091
		0.587	0.500	0.299	0.201
		0.761	0.697	0.318	0.379
	4.9	0.314	0.329	0.257	0.072
		0.587	0.522	0.288	0.235
		0.761	0.628	0.333	0.295
	6.1	0.314	0.261	0.182	0.079
		0.587	0.443	0.288	0.155
		0.761	0.500	0.413	0.087
20:10	1.2	0.893	0.871	0.151	0.719

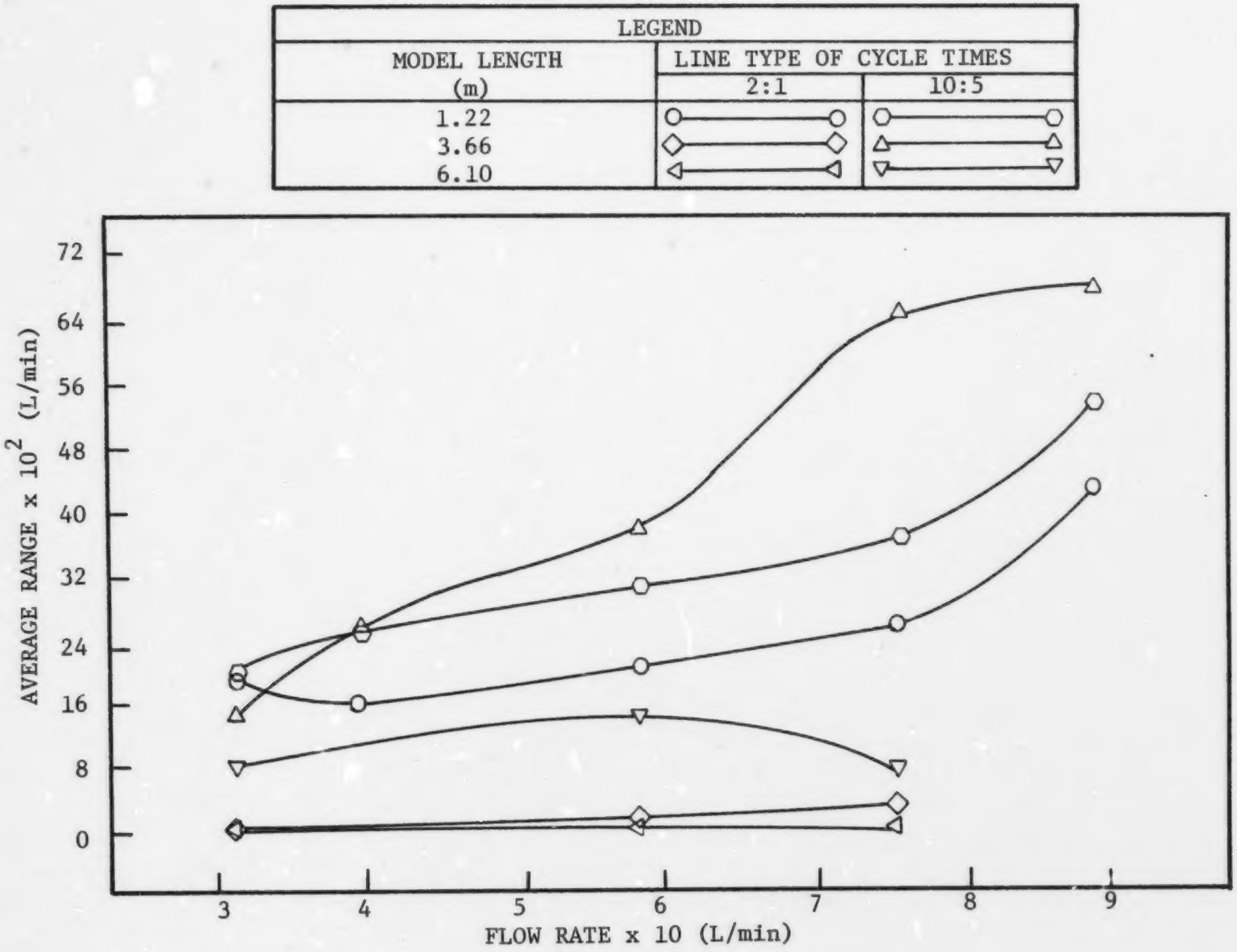

Figure 14. Model data: flow rate vs average range.

TABLE 34. MODEL DATA: CYCLE TIME VS AVERAGE RANGE

MODELED LENGTH (m)	APPLIED FLOW RATE (l/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
1.2	0.314	2:1	0.360	0.151	0.208
		4:2	0.367	0.151	0.216
		10:5	0.303	0.151	0.151
	0.397	2:1	0.379	0.208	0.170
		4:2	0.420	0.151	0.269
		10:5	0.424	0.151	0.273
	0.587	2:1	0.503	0.284	0.220
		4:2	0.560	0.223	0.337
		10:5	0.560	0.151	0.409
	0.761	2:1	0.750	0.473	0.276
		4:2	0.632	0.235	0.397
		10:5	0.848	0.151	0.697
	0.893	2:1	0.772	0.318	0.454
		4:2	0.814	0.235	0.579
		10:5	0.886	0.151	0.734
2.4	0.314	2:1	0.212	0.204	0.008
		4:2	0.265	0.197	0.072
		10:5	0.288	0.151	0.136
	0.397	2:1	0.257	0.235	0.023
		4:2	0.288	0.220	0.068
		10:5	0.341	0.182	0.159
	0.587	2:1	0.379	0.333	0.045
		4:2	0.401	0.288	0.114
		10:5	0.530	0.284	0.246

TABLE 34. (continued)

MODELED LENGTH (m)	APPLIED FLOW RATE (1/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
	0.761	2:1	0.507	0.462	0.045
		4:2	0.541	0.424	0.117
		10:5	0.689	0.322	0.367
	0.893	2:1	0.792	0.318	0.045
		4:2	0.572	0.432	0.140
		10:5	0.689	0.288	0.401
3.7	0.314	2:1	0.220	0.220	0.000
		4:2	0.220	0.204	0.015
		10:5	0.273	0.182	0.091
	0.587	2:1	0.371	0.356	0.015
		4:2	0.394	0.333	0.061
		10:5	0.500	0.299	0.201
	0.761	2:1	0.519	0.492	0.026
		4:2	0.538	0.447	0.091
		10:5	0.697	0.318	0.379
4.9	0.314	2:1	0.288	0.288	0.000
		4:2	0.220	0.204	0.015
		10:5	0.329	0.257	0.072
	0.587	2:1	0.386	0.371	0.015
		4:2	0.310	0.254	0.057
		10:5	0.522	0.288	0.235
	0.761	2:1	0.485	0.454	0.030
		4:2	0.556	0.454	0.102
		10:5	0.628	0.333	0.295

TABLE 34. (continued)

MODELED LENGTH (m)	APPLIED FLOW RATE (l/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
6.1	0.314	2:1	0.212	0.212	0.000
		4:2	0.227	0.212	0.015
		10:5	0.261	0.182	0.079
	0.587	2:1	0.326	0.326	0.000
		4:2	0.371	0.348	0.023
		10:5	0.443	0.288	0.155
	0.761	2:1	0.454	0.454	0.000
		4:2	0.439	0.439	0.000
		10:5	0.500	0.413	0.087
2.4	0.397	2:2	0.212	0.204	0.008
		4:4	0.288	0.182	0.110
		10:10	0.386	0.151	0.235
3.7	0.587	2:2	0.326	0.318	0.008
		4:4	0.363	0.295	0.068
		10:10	0.526	0.254	0.273
4.9	0.587	2:2	0.280	0.257	0.023
		4:4	0.326	0.223	0.102
		10:10	0.492	0.257	0.235
6.1	0.587	2:2	0.257	0.238	0.019
		4:4	0.295	0.220	0.076
		10:10	0.424	0.182	0.242

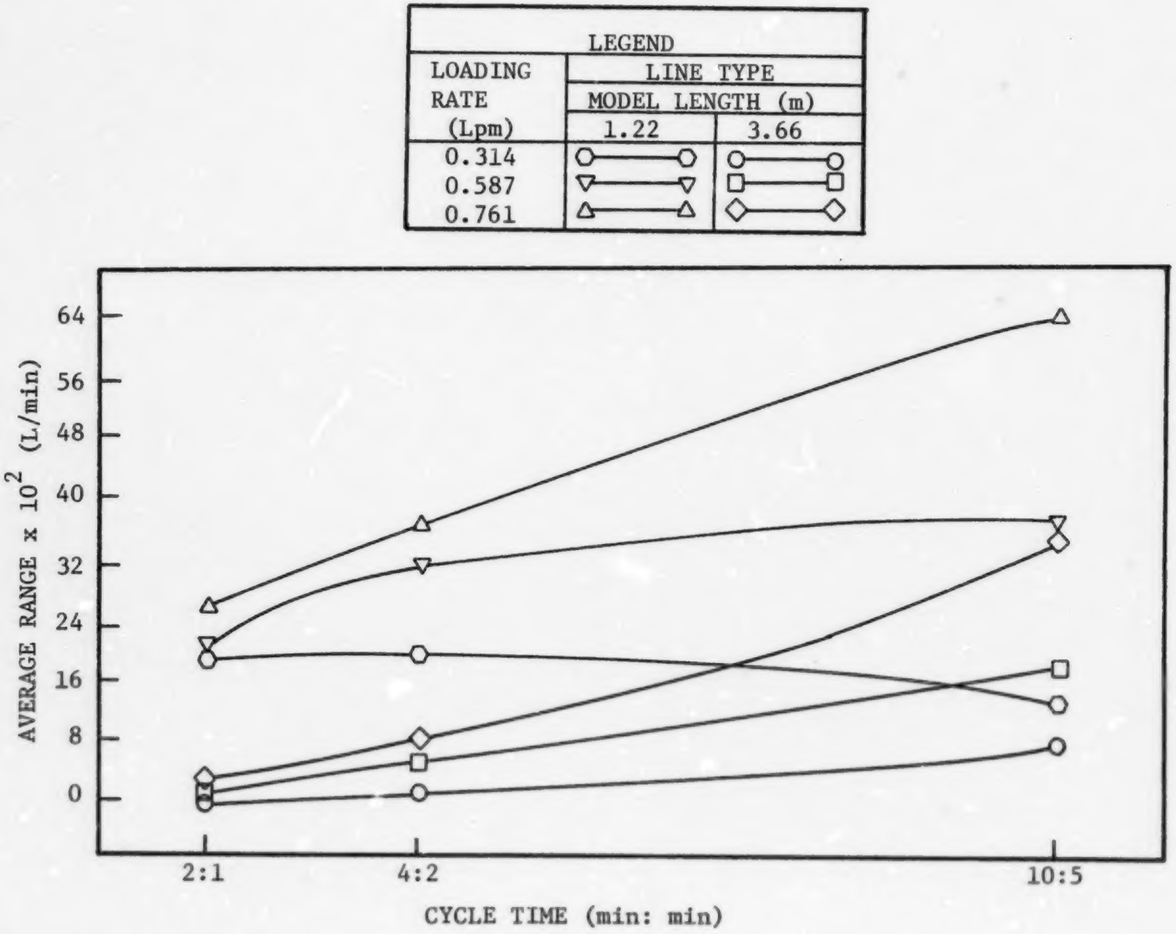

Figure 15. Model data: cycle time vs average range for 2/3 on to 1/3 off cycle ratio.

TABLE 35. MODEL DATA: CYCLE TIME VS AVERAGE RANGE FOR CYCLE RATIO COMPARISON

MODELED LENGTH (m)	APPLIED FLOW RATE (1/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
2.4	0.314	2:1	0.212	0.204	0.008
		4:2	0.265	0.197	0.072
		10:5	0.288	0.151	0.136
	0.397	2:2	0.212	0.204	0.008
		4:4	0.288	0.182	0.110
		10:10	0.386	0.151	0.235
3.7	0.587	2:1	0.371	0.356	0.015
		4:2	0.394	0.333	0.061
		10:5	0.500	0.299	0.201
		2:2	0.326	0.318	0.008
		4:4	0.363	0.295	0.068
		10:10	0.526	0.254	0.273
4.9	0.587	2:1	0.386	0.371	0.015
		4:2	0.310	0.254	0.057
		10:5	0.522	0.288	0.235
		2:2	0.280	0.257	0.023
		4:4	0.326	0.223	0.102
		10:10	0.492	0.257	0.235
6.1	0.587	2:1	0.326	0.326	0.000
		4:2	0.371	0.348	0.023
		10:5	0.443	0.288	0.155
		2:2	0.257	0.238	0.019
		4:4	0.295	0.220	0.076
		10:10	0.424	0.182	0.242

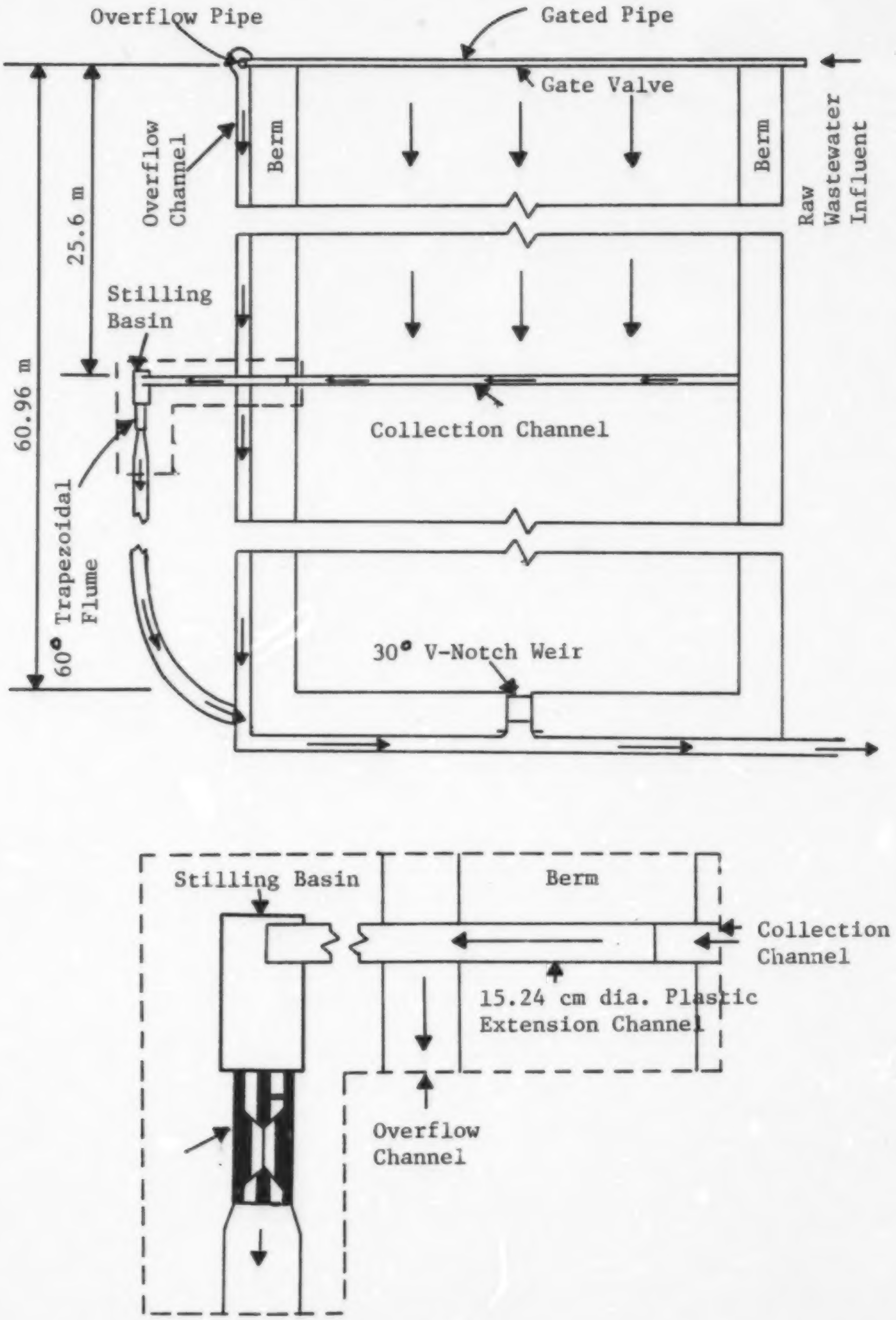
Overflow Pipe
Gated Pipe
Gate Valve
Overflow Channel
Berm
Berm
Raw Wastewater Influent
25.6 m
60.96 m
Stilling Basin
Collection Channel
60° Trapezoidal Flume
30° V-Notch Weir
Stilling Basin
Berm
Collection Channel
15.24 cm dia. Plastic Extension Channel
Overflow Channel

Figure 16. Schematic of prototype runoff collection system.

gate valve in the subsequent text. Figures 2 and 16 show the sliding gate valve. To surge the flow applied at the plot influent, the sliding gate valve was opened and closed manually, in conjunction with appropriate times on a stop watch. When the sliding gate valve was closed, the excess water was forced out an overflow pipe, shown in Figure 16, and directed around the plot. This overflow also served to keep the head on the sliding gate valve constant, thereby insuring a constant flow rate at the sliding gate valve. The only requirement was that the sliding gate valve be opened to the same position every time and that water continue to run out the overflow pipe.

A small channel was cut across the plot to collect the runoff at the bottom of the test section. A section of 15.24 cm pipe was then split in half and installed to extend the channel to a trapezoidal 60 degree flume. Figure 16 shows a schematic of the field runoff collection and measurement system, and Figure 17 shows the runoff measuring device.

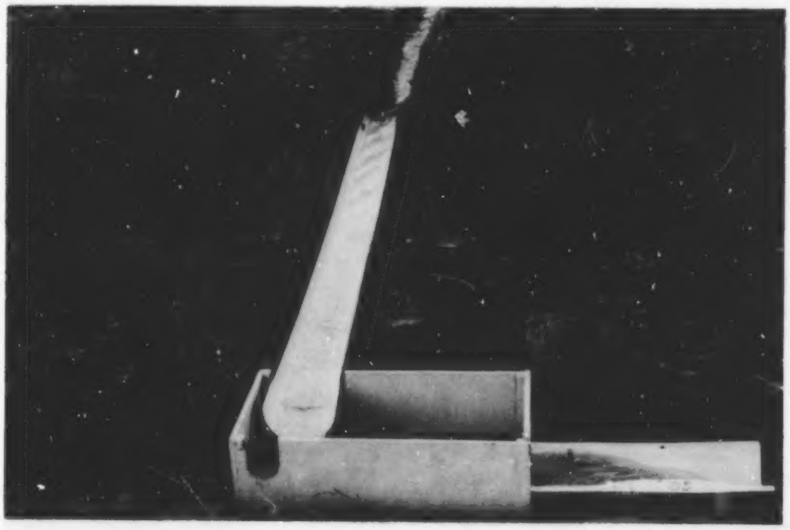

Figure 17. Field Runoff Measurement System

Field tests were done using influent flow rates of 43.15, 113.56, and 216.90 l/min surged at cycle times of 10:5, 10:10, and 10:20 corresponding to 0.33, 0.87, and 1.67 l/min in the model. While the influent flow was surged manually, head readings were recorded every thirty seconds at the runoff flume. These tests were performed at field lengths of 8.53, 17.07, 25.6, 34.14, 42.67, and 51.21 m, matching model lengths of 1.22, 2.44, 3.66, 4.88, 6.10, and 7.32 m. The head measurements taken at the flume were then used to calculate the instantaneous runoff flow rate.

The field test procedures that were followed were:

1. At the beginning of the field testing, the sliding gate valve at the influent was calibrated and marked to insure test flow rates of 43.15, 113.56, and 216.90 l/min.

2. For the first test of the day, the sliding gate valve was fully opened until water ran off the bottom of the plot into the collection channel. This was done to wet the surface and fill the dead storage requirements of the test section.

3. After the sliding gate valve was closed (either post initial surface saturation or post test run) the flume was observed until the head was below 3.81 cm before the next test was started.

4. To begin the test, the influent sliding gate valve was opened to the correct flow mark, and simultaneously, a stop watch was started to keep track of time. The sliding gate valve was then manually operated to surge the influent flow rate to the tested cycle time. Simultaneously, head readings were taken every thirty seconds at the runoff flume for time periods ranging from 70 to 120 minutes.

These procedures were followed in an effort to get test results consistent with a saturated surface and to insure uniformity between all experiments.

Field Data Analysis

The instantaneous runoff flow rate data recorded in the field were plotted against time to give runoff hydrographs. Figure 18 shows these. Again, as in the model, these hydrographs were studied to determine the relationship between the average range value and damping length, flow rate and cycle time. To keep the field analysis parallel to the model study, these parameters were looked at in the same fashion as the model data.

Figure 19 was developed from Table 36. It shows field length versus average range. A reduction in the average range value as the field length increases is shown to exist by the lines of equal flow rate and cycle time. Figure 19 implies that a flow rate of 43.15 l/min applied in a surge flow cycle of 10:5 would require a damping length of 17.07 m and would result in a continuous flow pattern of 24.61 l/min throughout the remaining length of the plot. The loading rate for water applied in this method would be approximately 1726 l/hr. This matches the design loading rate for this plot. This suggests that applying the water at the present design loading, using a 10 minute on to 5 minute off cycle time, would simulate a continuous flow application without a plugging problem resulting. This result coincided with the model at the 45.05 l/min loading rate applied at the 10:5 cycle time. The next application which resulted in a zero average range value was the application of 113.56 l/min at a cycle time of 10:5. This loading rate which is larger than any required in the design of this treatment project was damped in a length of 34.14 m. Lengths of this magnitude would probably be excessive. The most important information in this graph was that water applied to the overland flow plot by the surge flow method was damped out

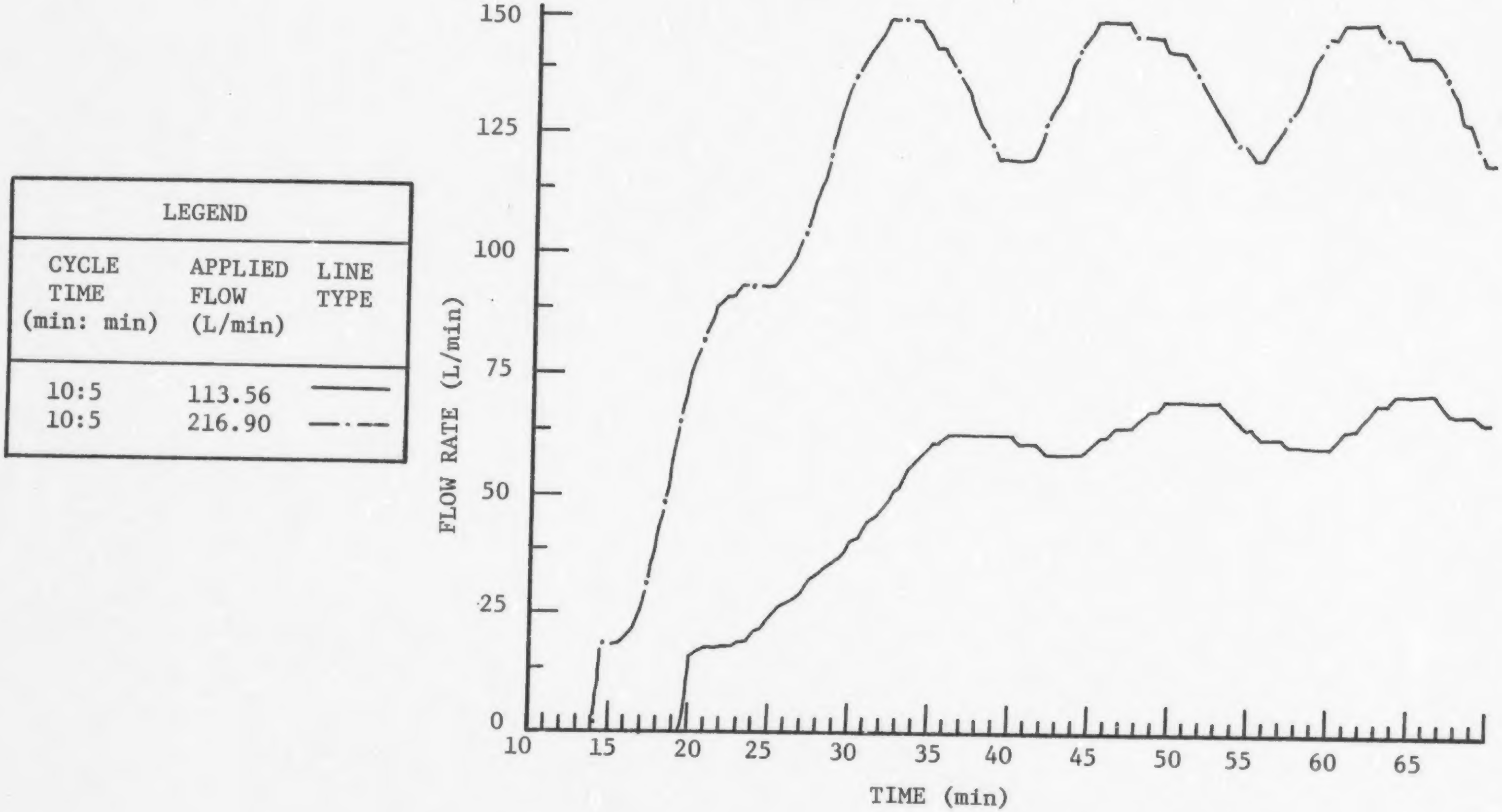

Figure 18. Prototype runoff hydrograph (25.6 m).

TABLE 36. PROTOTYPE DATA: FIELD LENGTH VS AVERAGE RANGE

CYCLE TIME ON:OFF (min:min)	APPLIED FLOW RATE (1/min)	PROTOTYPE LENGTH (m)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
2:1	43.2	8.5	28.4	28.4	0.0
	113.6	8.5	77.6	75.0	2.6
5:10	113.6	17.0	41.6	28.4	13.2
	216.9	17.0	96.5	41.6	54.9
10:5	43.2	8.5	37.9	20.8	17.0
		17.0	24.6	24.6	0.0
	113.6	8.5	96.5	47.3	49.2
		17.0	89.0	53.0	36.0
		25.6	73.8	62.5	11.4
		34.0	41.6	41.6	0.0
		42.7	47.3	47.3	0.0
	216.9	25.6	151.4	121.1	30.3
		34.0	136.3	102.2	34.0
		42.7	132.5	115.5	17.0
		51.2	107.9	100.3	7.6
10:10	43.2	17.0	13.2	13.2	0.0
	113.6	8.5	96.5	26.5	70.0
		17.0	71.9	34.0	37.9
		25.6	62.5	47.3	15.1
		34.0	49.2	36.0	13.2
		42.7	32.2	32.2	0.0
	216.9	25.6	143.8	75.7	68.1
		34.0	119.2	68.1	51.1
		42.7	109.8	75.7	34.0
		51.2	79.5	62.5	17.0

TABLE 36. (continued)

CYCLE TIME ON:OFF (min:min)	APPLIED FLOW RATE (1/min)	PROTOTYPE LENGTH (m)	PEAK FLOW RATE (1/min)	VALLEY FLOW RATE (1/min)	AVERAGE RANGE (1/min)
10:20	113.6	8.5	92.7	17.0	75.7
		17.0	60.6	18.9	41.6
		25.6	36.0	20.8	15.1
		34.0	28.4	18.9	9.5
		42.7	17.0	17.0	0.0
	216.9	25.6	115.5	32.2	83.3
		34.0	100.3	36.0	64.4
		42.7	54.9	17.0	37.9
		51.2	60.6	32.2	28.4
20:10	113.6	17.0	104.1	32.2	71.9

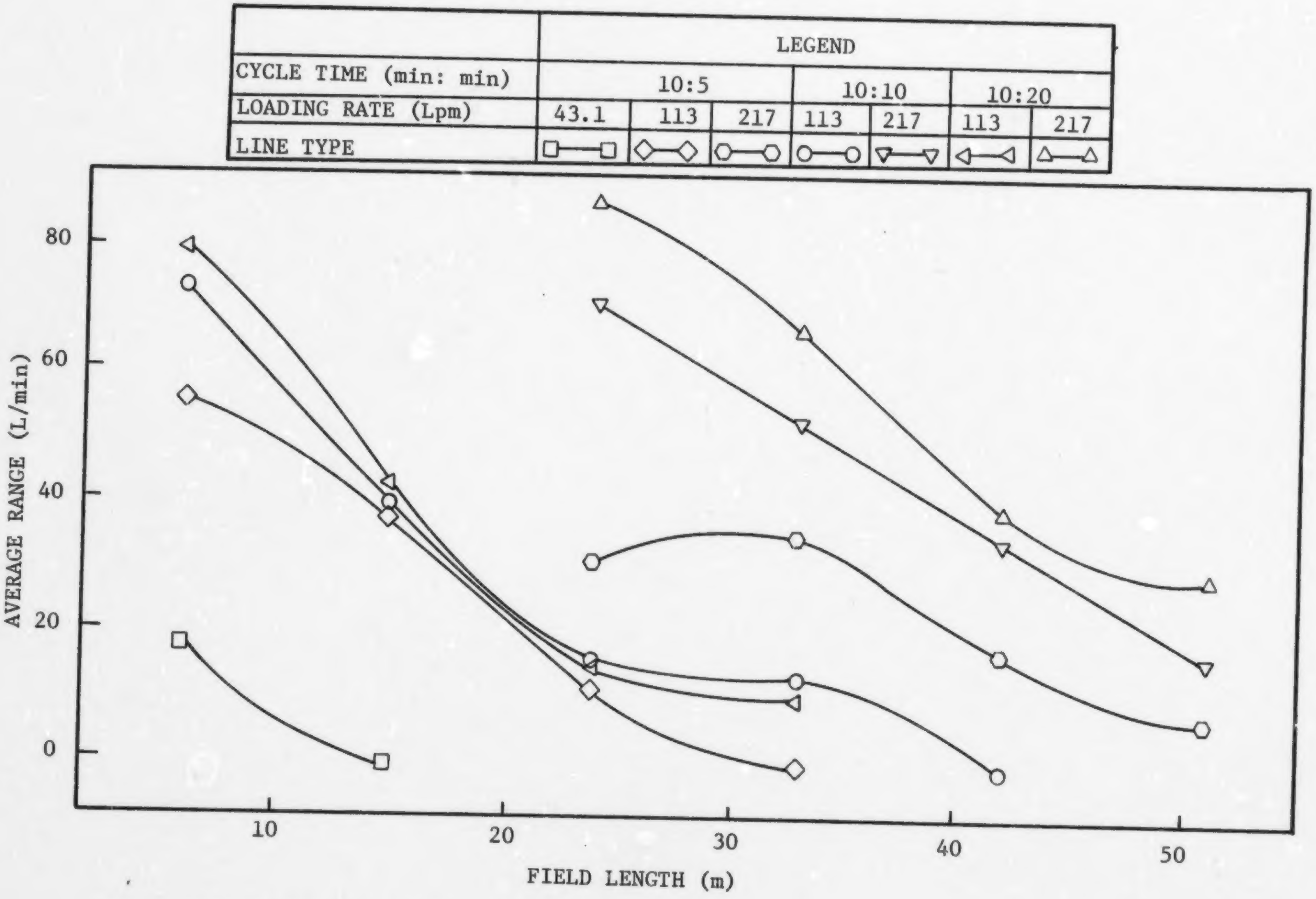

Figure 19. Prototype data: field length vs average range.

TABLE 37. PROTOTYPE DATA: FLOW RATE VS AVERAGE RANGE

CYCLE TIME ON:OFF (min:min)	PROTOTYPE LENGTH (m)	APPLIED FLOW RATE (l/min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
2:1	8.5	43.2	28.4	28.4	0.0
		113.6	77.6	75.0	2.6
5:10	17.0	113.6	41.6	28.4	13.2
		216.9	96.5	41.6	54.9
10:5	8.5	43.2	37.9	20.8	17.0
		113.6	96.5	47.3	49.2
	17.0	43.2	24.6	24.6	0.0
		113.6	89.0	53.0	36.0
	25.6	113.6	73.8	62.5	11.4
		216.9	151.4	121.1	30.3
	34.0	113.6	41.6	41.6	0.0
		216.9	136.3	102.2	34.0
	42.7	113.6	47.3	47.3	0.0
		216.9	132.5	115.5	17.0
	51.2	216.9	107.9	100.3	7.6
10:10	8.5	113.6	96.5	26.5	70.0
	17.0	43.2	13.2	13.2	0.0
		113.6	71.9	34.0	37.9
	25.6	113.6	62.5	47.3	15.1
		216.9	143.8	75.7	68.1
	34.0	113.6	49.2	36.0	13.2
		216.9	119.2	68.1	51.1

TABLE 37. (continued)

CYCLE TIME ON:OFF (min:min)	PROTOTYPE LENGTH (m)	APPLIED FLOW RATE (l/min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
10:10	42.7	113.6	32.2	32.2	0.0
		216.9	109.8	75.7	34.0
	51.2	216.9	79.5	62.5	17.0
10:20	8.5	113.6	92.7	17.0	75.7
	17.0	113.6	60.6	18.9	41.6
	25.6	113.6	36.0	20.8	15.1
		216.9	115.5	32.2	83.3
	34.0	113.6	28.4	18.9	9.5
		216.9	100.3	36.0	64.4
	42.7	113.6	17.0	17.0	0.0
		216.9	54.9	17.0	37.9
	51.2	216.9	60.6	32.2	28.4

TABLE 38. PROTOTYPE DATA: CYCLE TIME VS AVERAGE RANGE

PROTOTYPE LENGTH (m)	APPLIED FLOW RATE (l/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
8.5	43.2	2:1	28.4	28.4	0.0
		10:5	37.9	20.8	17.0
	113.6	2:1	77.6	75.0	2.6
		10:5	96.5	47.3	49.2
		10:10	96.5	26.5	70.0
		10:20	92.7	17.0	75.7
17.0	42.2	10:5	24.6	24.6	0.0
		10:10	13.2	13.2	0.0
	113.6	5:10	41.6	28.4	13.2
		10:5	89.0	53.0	36.0
		10:10	71.9	34.1	37.9
		10:20	60.6	18.9	41.6
		20:10	104.1	32.2	71.9
	216.9	5:10	96.5	41.6	54.9
25.6	113.6	10:5	73.8	62.5	11.4
		10:10	62.5	47.3	15.1
		10:20	36.0	20.8	15.1
	216.9	10:5	151.4	121.1	30.3
		10:10	143.8	75.7	68.1
		10:20	115.5	32.2	83.3

TABLE 38. (continued)

PROTOTYPE LENGTH (m)	APPLIED FLOW RATE (l/min)	CYCLE TIME ON:OFF (min:min)	PEAK FLOW RATE (l/min)	VALLEY FLOW RATE (l/min)	AVERAGE RANGE (l/min)
34.0	113.6	10:5	41.6	41.6	0.0
		10:10	49.2	36.0	13.2
		10:20	28.4	18.9	9.5
	216.9	10:5	136.3	102.2	34.1
		10:10	119.2	68.1	51.1
		10:20	100.3	36.0	64.4
42.7	113.6	10:5	47.3	47.3	0.0
		10:10	32.2	32.2	0.0
		10:20	17.0	17.0	0.0
	216.9	10:5	132.5	115.5	17.0
		10:10	109.8	75.7	34.1
		10:20	54.9	17.0	37.9
51.2	216.9	10:5	107.9	100.3	7.6
		10:10	79.5	62.5	17.0
		10:20	60.6	32.2	28.4

rather than continuing in a surge flow pattern down the entire plot length. This means that the surface roughness impedes the flow simulates a continuous runoff pattern.

Figure 20, developed from Table 37 was used to determine what average range values could be expected at various hydraulic loadings with surge flow application. Since only three different application rates were tested, the data here are severely limited. It was noted that the average range value could be expected to increase with increased loadings.

The last parameter studied was the cycle time effect on average range. First of all, a time cycle ratio must be selected before the cycle time. Since the model test mainly covered the average range value changes due to cycle time changes within a set time cycle ratio, the field tests were slanted toward changing time cycle ratios. It was hoped that the average range would not change too drastically with time cycle ratios of longer off time periods. If this was the case, the larger loading rates inherent to these time cycle ratios of longer off time could be used. This would allow opening the sliding gate valves wider for the same loading rate as the 2/3 on to 1/3 off time cycle ratio.

Figure 21 was developed from Table 38. This graph shows average range versus cycle time. Before analyzing this graph, it should be noted that the loading rates were not altered to be consistent between the different time cycle ratios. This means the average range value for the time cycle ratios of the longer off times will be smaller due to the smaller loading rate, and not solely because of the changing time cycle ratios. The table below exhibits this difference by showing the loading rates for the different flow rates and cycle times.

TABLE 39. LOADING RATES (1/hr)

FLOW RATE (1/min)	CYCLE TIME (min:min) 10:5	10:10	10:20
43.15	1726	1295	863
113.56	4542	3407	2271
216.90	8675	6506	4338

The difference in average range value between time cycle ratios for the same flow rate should not be as extensive as would be expected if the loading rate had been the same for all the time cycle ratios. In an effort to back this up, the average range of the 4542 1/hr loading rate at the 10:5 cycle time was compared to the average range of the loading rate of 4338 1/hr at the 10:20 cycle time. At the 25.6 m and 34.14 m field lengths, the 10:5 cycle time at 113.56 1/min had an average range value of 11.36 and 0 1/min, respectively. At the same field lengths, the average range value for the 10:20 cycle time were 83.28 and 64.35 1/min, respectively. This shows a large

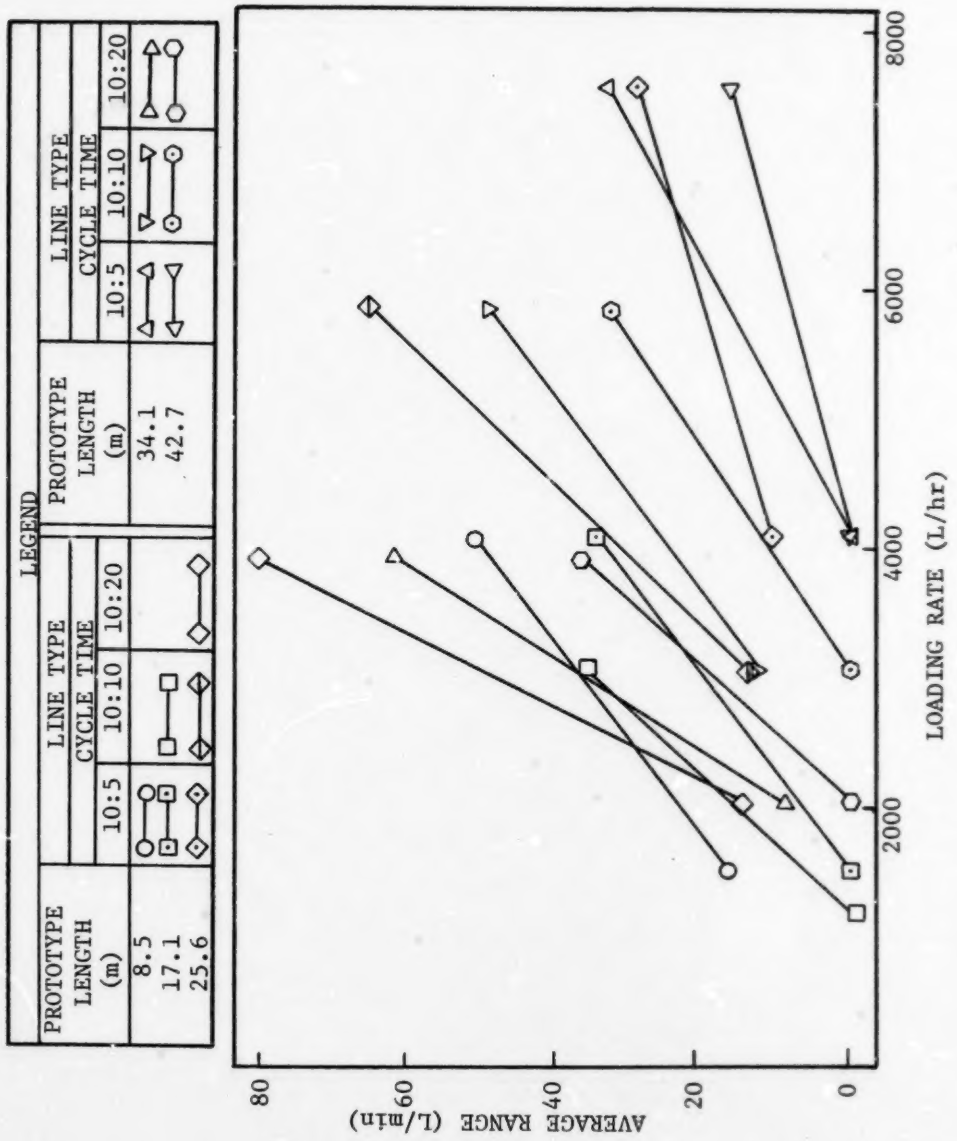

Figure 20. Prototype data: loading rate vs average range.

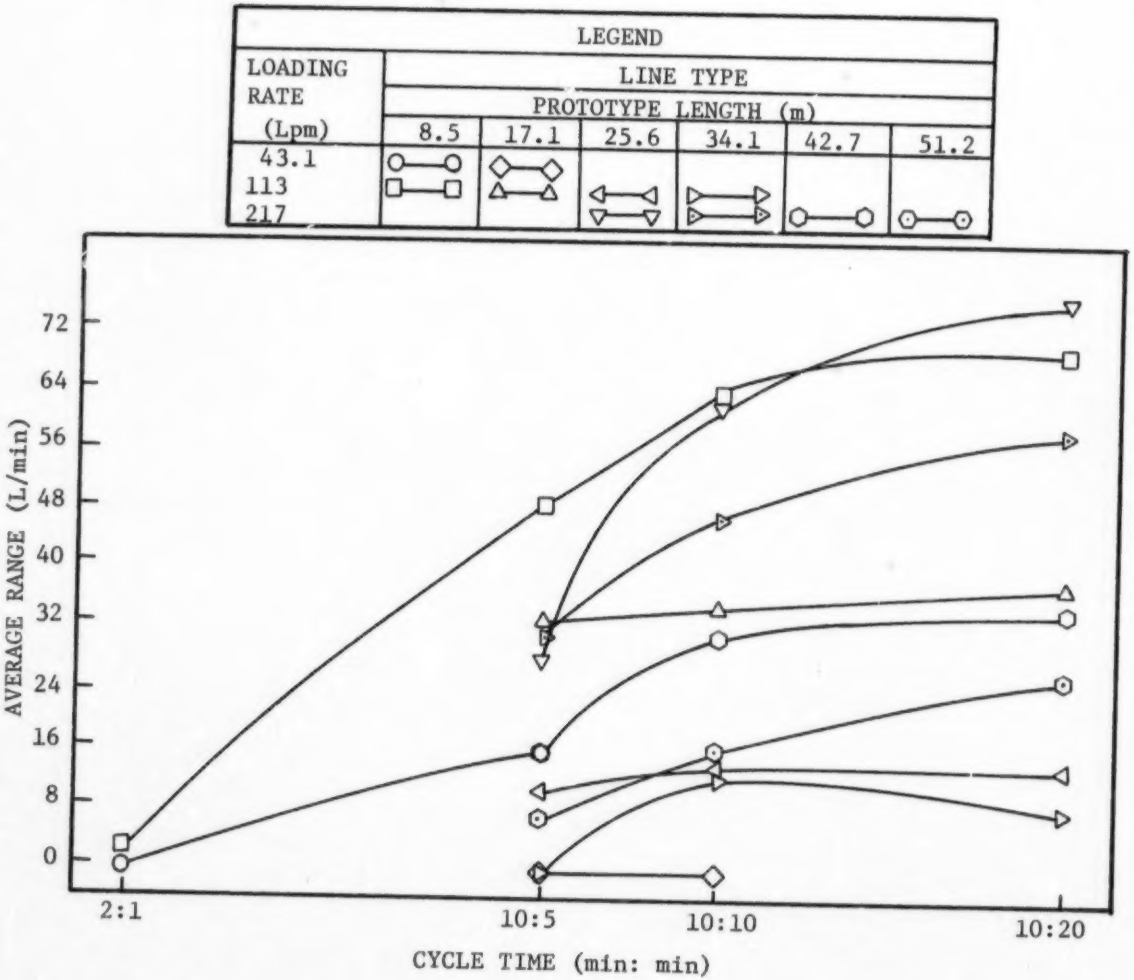

Figure 21. Prototype data: cycle time vs average range.

average range value increase between the time cycle ratios at a loading rate that is close to compatibility. These observations imply that time cycle ratios of longer off time will cause an unfeasible gain in the average range value. Another observation from Figure 21 was that the 2:1 cycle time test at 8.53 m supported the model test finding--that large cycle times lead to larger average range values. The main problem that a designer will run into by using the shorter cycle times is that the mechanical devices being used to surge the influent flow may not be capable of handling the extra work load. A designer may be exposing his equipment to an overwhelming work load by using the very short cycle times.

It should be realized that flow rate, cycle time, and damping length are all interrelated to average range. The average range value of the runoff flow pattern can be altered by changing any one of the three. For this reason only, trends could be established by analyzing them separately.

To help in the simultaneous selection of loading rate, damping length and cycle time, Figure 22 was developed from Table 40. This graph has lines of zero average range drawn for specific cycle times between loading rate and damping length. Since the design of an overland flow treatment system usually requires a certain loading rate to provide good water treatment, this is usually a known value. Using the set value, a cycle time can be chosen to give an average range value of zero at a desired damping length. If any one of the three parameters is known, the same can be done to get the other two. Some freedom can be used in these selections if the zero average range value is not required and a small amount of average range can be tolerated.

Figure 22 was drawn based on a small amount of data and should be used only as an estimate of the average range to be expected. Also, for this graph to be applicable the overland flow plots should have the same approximate slope, surface roughness and general characteristics as the prototype (field plot) tested here.

The surge flow field test results indicated:

1. The time cycle ratio of 2/3 on to 1/3 off resulted in a runoff flow pattern of the smallest average range for time cycle ratios of shorter on times.
2. Average range is a function of damping length, loading rate, and cycle time. The trend of the relationship between these three parameters and the average range is:
    a. Longer damping length results in a runoff flow pattern of a smaller average range value.
    b. Shorter cycle times reduce the average range values.
    c. Smaller loading rates result in less intense average range values.
3. Figure 22 can be used to estimate the loading rate, cycle time, and damping length for a surge overland flow water treatment system.

TABLE 40. PROTOTYPE DATA: AVERAGE RANGE VALUES FOR CYCLE TIME, LOADING RATE, AND DAMPING LENGTH

CYCLE TIME ON:OFF (min:min)	LOADING RATE (1/hr)	AVERAGE RANGE (1/min) FOR DAMPING LENGTHS (m)						
		8.5	17.0	25.6	34.0	42.7	51.2	59.7
2:1	1726.0	0.0						
	4542.0	2.6						
5:10	2271.0		13.2					
	4337.6		54.9					
10:5	1726.0	17.0	0.0					
	4542.0	53.0	36.0	11.4	0.0			
	8675.2			30.3	34.1	17.0	7.6	0.0
10:10	1294.5		0.0					
	3406.5	70.0	37.9	15.1	13.2	0.0		
	6506.4			68.1	51.1	34.1	17.0	0.0
10:20	2271.0	75.7	41.6	15.1	9.5	0.0		
	4337.6			83.3	64.4	37.9	28.4	0.0

LEGEND							
CYCLE TIME (min: min)	LOADING RATE (Lph)	PROTOTYPE LENGTH (m)	POINT DESCRIPTION	CYCLE TIME (min: min)	LOADING RATE (Lph)	PROTOTYPE LENGTH (m)	POINT DESCRIPTION
2:1	1726	8.5	○	10:10	1294	17.1	□
	4542	8.5	○		3407	42.7	△
10:5	1726	17.1	⊙		6506	51.2	◁
	4542	34.1	◇	10:20	2271	42.7	▷
	8675	51.2	▽		4338	51.2	⊙

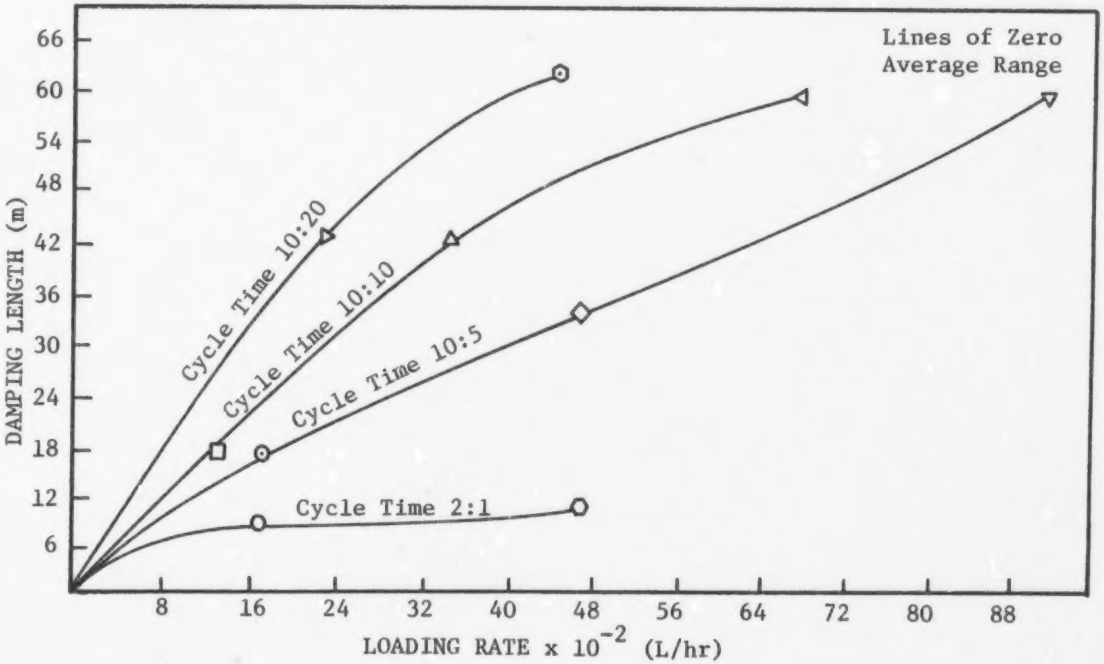

Figure 22. Prototype data: graph for parameter selection at zero average range values.

Results and Conclusions

A comparison between model and field (prototype) data was made to show how well the model information predicted the field situation. Equation (1) was used to modify the model flow rates to compatible field flow rates. Figure 23 is a plot of model and field hydrographs in which the model flow rates have been converted to approximate equivalent field values. It should be noted that the modified model flow rate was 98.8 l/min at the 10:5 cycle time. This leads to a loading rate of 4012 l/hr, while the field data had a 113.56 l/min instantaneous flow rate for a loading rate of 4542 l/hr at the 10:5 cycle time. The small difference in flow rate and loading rate is caused because the orifice sizes in the model were not set exactly to the slide gate opening in the field test. Even though the model flow rate was smaller, the modified model hydrograph had a peak value of 90.85 l/min, a valley value of 41.64 l/min and an average range value of 49.21 l/min. The corresponding values for the field data were 73.82 peak, 62.46 valley and an average range value of only 11.36 l/min. This same trend was found for all cases, indicating that the model predicted greater variations than the actual field data, but that the trends were similar. Listed below are some reasons that may be responsible for the large discrepancies between the model and field tests:

1. The roughness of the artificial turf did not meet the modeling requirements of the Reynold's number for the natural grass of the prototype (field situation). This resulted in a model turf of a smaller surface roughness value than that of the field's natural grass.

2. Evapotranspiration and infiltration losses existed in the field, but not in the model experiments.

3. The model surface was smoother and more uniform giving it less dead storage volume than the field plot.

Because of these inconsistencies, the model hydrographs were not compared with the field's; rather, the results of each were used individually to unveil surge flow trends common to both.

In the analysis of both the model and field data, three principles of surge flow were verified. They indicate that the surge flow runoff pattern initiated by the intermittent water application at the influent can be damped to simulate a continuous flow runoff pattern by:

1. Lengthening the damping section of the overland flow plot.

2. Decreasing the loading rate applied at the influent.

3. Using exclusively time cycle ratios containing the longer on times in conjunction with shorter off time periods, such as the 2/3 on to 1/3 off time cycle ratio.

4. Shortening the on and off cycle time periods.

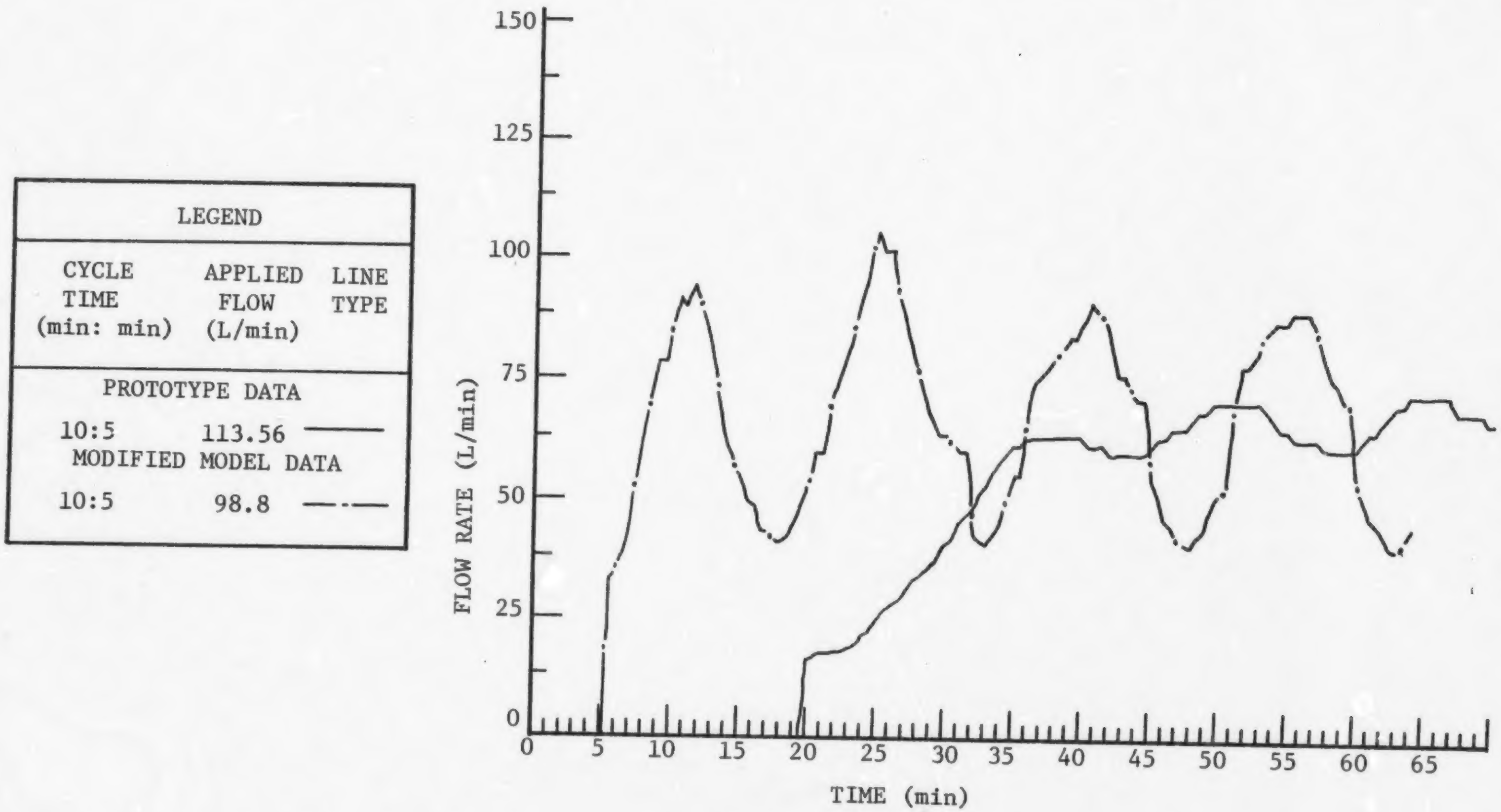

Figure 23. Modified model runoff hydrograph (3.7 m) and prototype runoff hydrograph (25.6).

Some major problems exist with altering just one of these parameters. For example, when the damping section of the plot is lengthened, an increase in wetted surface area will cause a rise in evapotranspiration, increased infiltration losses, and an increase in overall size of the overland flow plots which will result in higher construction costs. Because of these inherent problems, the damping length should be selected with the shortest length possible for the given conditions.

Caution should also be taken when adjusting the loading rate. The loading rate is usually specified at levels that are conducive to quality water treatment. Tampering with this value may lead to problems in treatment quality. When surge flow is used in the overland flow treatment system, the slide gate opening at the influent should be computed first. The experience of running the overland flow prototype shows that a slide gate opening of less than 0.635 cm could be expected to cause a plugging problem, especially when raw wastewater is applied. The exact slide gate opening size through which solids of the raw or primary wastewater will pass without plugging was not determined. If this value could be found, it could be used as a minimum size for which continuous flow application is practical. Loading through more than one slide gate using surge flow methods, could be considered for slide gate openings at or above this determined minimum size. Dispensing the flow through more than one slide gate on the plot would result in more uniformity of flow across and down the plot, although the grass is very effective in uniformly spreading the water across the plot. It should be emphasized that the loading rate is not as flexible a parameter as the others in getting the desirable surge flow runoff characteristics. Surge flow design must consider the operational loading ranges for effective treatment of the wastewater so that changes in the loading rate are done within the bounds of good water treatment.

The most flexible parameter in an overland surge flow treatment system is the cycle time. About the only bounds to its selection is the ability of the mechanical devices used to surge the flow. This research and others (Bishop, 1980) have shown that a continuous runoff flow pattern can be mimicked best by using the shorter on and off times; thus, an impossible work load could be placed on the equipment. In spite of this limitation, the choice of a cycle time is the most flexible in obtaining the desired runoff pattern. Because of this fact, the choice should be made based on consideration of the desired loading rate and damping length.

To aid in the simultaneous selection of the surge flow parameters, Figure 22, which was discussed earlier, was developed. Figure 22 relates a zero average range value to damping length, loading rate, and cycle time. As an example of its use, a surge flow design was calculated for plot 1. Starting with the specified loading rate of 1741 l/hr, the slide gate opening was calculated to be .457 cm. This opening size is just smaller than the 0.635 cm valve required, and therefore, warranted the use of surge flow. Figure 22 shows a cycle time of 10:5 would lead to a damping length of 17.07 m, and a cycle time of 2:1 would give a 8.53 m damping length. At this point, the designer should consider his surge equipment to determine if the shorter damping length or the longer cycle time is more important to the smooth operation of the system. Once the final damping length is determined, it should be added to the water treatment section to give a total plot length.

Hopefully, future surge flow research will include data on the relationship between average range and the amount of wastewater treatment accomplished. This discovery may lead to the use of longer cycle times or shorter plot damping length requirements because the presence of some average range value in the plot runoff may not cause a significant drop in the quality of treatment.

It should be emphasized that Figure 22 is by no means a complete design alternative. Only a limited amount of data was available in its development, and it should be used only as a guideline to the selection of cycle time for an overland flow plot which has similar slope and surface roughness to that of the prototype tested.

The following conclusions can be made from the analysis of surge flow on gated pipe :

1. The 2/3 on to 1/3 off time cycle ratio is the most advantageous ratio to use when trying to simulate a continuous flow pattern in the shortest damping length possible.

2. Surge flow damping to a continuous flow pattern can be attained by extending the field damping length, decreasing the loading rate, or by using a shorter cycle time.

3. Figure 22 was developed as a guide to attain a zero average range by selecting the proper cycle time to get a desired damping length for a particular loading rate.

With the knowledge of the above trends, the designer of an overland flow wastewater treatment system will have the tools necessary for a more efficient design. The major benefits of using surge flow are listed below:

1. It will help solve the influent plugging problem at the lower application rates necessary for good water treatment.

2. It will allow automation of overland flow water treatment systems by providing a dependable water delivery system.

These benefits alone should make it feasible to install and maintain a surge flow water delivery system.

It is recommended that more research be done to better define the properties of surge flow. Below are some suggestions to improve the quality of future surge flow research on an overland flow plot:

1. Instantaneous flow rates should be adjusted in each individual test to maintain a consistency between loading rates of different time cycle ratios.

2. The manual surging of the plot influent, as well as the recording of the runoff flow measurement, should be done automatically with some sort of surging valve and a staff gauge recorder. This would lead to better quality and larger quantities of runoff data.

3. Tests for the purpose of comparison with the surge flow data should be run for the continuous flow application.

4. Tests should be run to determine the smallest slide gate opening size that one can use to avoid plugging of the slide gate by raw or primary wastewater.

5. Test the 2/3 on to 1/3 off time cycle ratio more extensively in the field to establish a more complete guideline for selecting cycle time.

6. Test the surge flow when influent is applied out of more than one slide gate for uniformity of application across and down the plot.

7. During surge flow applications of wastewater, take and analyze water samples from the runoff. Therefore, the relationship between average range and degree of water treatment may be established and an acceptable average range value determined.

8. Design test procedures that are amenable to keeping a water budget. This water budget will make it possible to study infiltration and evapotranspiration losses in relation to changing cycle times.

9. Test several different species of overland flow grass to obtain surge flow data on a variety of surface roughnesses.

In addition to the use of surge flow to help alleviate the influent plugging problem, the following suggestions should be incorporated into the water delivery system:

1. Use treatment to eliminate a portion of the suspended solids.

2. Use a circular orifice opening which would be more effective at passing solids than the rectangular openings provided with the slide gates on gated pipe.

3. Use a surge reservoir upstream of the overland flow plot influent so that the correct pressure and surge flow rate are maintained in order to satisfy the design loading rate.

These design ideas, along with the incorporation of a surge flow water application technique, could make overland flow treatment of wastewater using a gated pipe wastewater influent a viable and reliable system.

APPENDIX D

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This research is an extension of research performed to better understand the overland flow wastewater treatment process. The literature on wastewater treatment processes makes it clear that overland flow is a viable wastewater treatment system; but, it is also complex, requires expertise from several areas, and is not a technology that can be used in all locations.

USE OF OVERLAND FLOW WASTEWATER TREATMENT AND ITS ADVANTAGES

While land treatment of municipal, agricultural, and industrial wastes is an ancient practice, overland flow is a relatively new process for wastewater treatment in the United States (Stevens, 1972; Pound and Crites, 1975). The longest operating overland flow system still in existence is the system at Melbourne, Australia (Seabrook, 1975). Land treatment of wastewater is said to be comparable in treatment level to conventional tertiary wastewater treatment for the removal of biological oxygen demand (BOD_5), phophorus, and nitrogen. And is is said to be excellent in the removal of heavy metals, insecticides, and pathogenic viruses (Stevens, 1972). Bastian (1982) presents a strong case for the use of land treatment systems for small communities. However, the feasibility study for Montgomery County, Maryland, by Powell & Culp (1975), demonstrated the weaknesses of considering land application for large wastewater systems.

A number of authors have stated the advantages of overland flow systems (Stevens, 1972; Seabrook, 1975; March, 1975; Smith and Schroeder, 1983; Martel, et al., 1982; Hall et al., 1979; Thomas et al., 1979; Witherow, 1981; Abernathy, 1983). The advantages are: 1) low cost of design, construction, operation, and maintenance; 2) effluent that meets or exceeds secondary effluent quality; 3) use of land generally unsuited to agricultural uses; 4) possible production of a cash crop; 5) creation of wildlife habitat; 6) potential improved management of sewage solids; 7) decreased staff training requirements; 8) low energy requirements; 9) minimal odor problems; 10) ability of the system to reliably withstand large variations in the strength of the applied wastewater; 11) lack of sludge production except by possible pretreatment process; 12) removal of nitrogen and phosphorus; and 13) conservation of water in the treatment process as compared to slow rate land treatment systems.

Since the process involves long periods of soil surface flooding, it is debatable if overland flow can be used to produce a cash crop. Seabrook (1975), however, reported that Melbourne, Australia uses wastewater for crop irrigation in the summer and then uses overland flow to treat the wastewater in the winter. Cattle and sheep are raised on the overland flow sites, and the returns from livestock sales nearly cover the costs of Melbourne's entire land treatment system.

Hall et al. (1979) commented on the large quantity of forage cut from their plots. They stated that forage could be harvested with conventional haying equipment without damage to the plots, providing sufficient time (5-10 days) was allowed for the soil to dry before harvesting. However, caution should be used before forage is fed to animals. Borrelli et al. (1978) found levels of NO_3 in forage from a field sprayed with wastewater to be close to toxic levels. By virtue of the fact that overland flow systems apply water at three to five times the amount required to meet evapotranspiration rates, forage production would be a secondary consideration to the treatment of the wastewater.

PLANNING, COSTS, AND DESIGN OF OVERLAND FLOW SYSTEMS

In planning an overland flow wastewater treatment system, there are many site considerations to be made before construction commences. There must be land available to meet the criteria for overland flow systems. Christensen (1982) discusses land acquisition methods. Factors to consider when choosing a site include: location, topography, geology, hydrology, agronomy, soil type, climate, vegetation, evapotranspiration rates, the quality of water to be applied, the amount of water to be treated, effluent disposal problems and the possible availability of winter storage reservoir sites (Dean, 1974). Numerous references review the importance of these factors and how they should be investigated when choosing a land treatment site (Stevens, 1972, Elliott, 1977; U.S. EPA, et al., 1974; U.S. EPA, 1975; Pound and Crites, 1975). Elliott et al. (1977) discuss management considerations for various climates. Palazzo et al. (1980) recommends orchardgrass and tall fescue as grasses that could be easily established and would survive in overland flow plots. They found that Kentucky bluegrass would invade overland flow plots, survive, and produce quality forage. Borrelli et al. (1978) recommends 'Garrison' creeping meadow foxtail for a winter spray irrigated field, and this specie should also survive in overland flow systems.

Site design and costs are discussed and existing designs compared in the following publications: (Stevens, 1972; Dean, 1974; U.S. EPA, et al., 1974; U.S. EPA, 1975; Thomas, et al., 1976; Abernathy, 1983; Harvey, 1976; Dept. of Army, 1980; Enviro Control, Inc., 1980; Smith and Schroeder, 1983). Stevens (1972) mentions the possible reuse or ground water recharge of renovated wastewater. He presents a summary chart of the costs of past projects, outlines the different labor requirements and costs involved in land treatment processes, and compares them to tertiary treatment costs. EPA (1975) provides an evaluation checklist for land treatment, a management plan, and an operation and maintenance manual. Abernathy (1983) presents an overview of a large-scale municipal overland flow system, listing costs for an application rate of 378,000 liters per day. Design considerations for farmers are discussed by March (1975), including soil type and irrigation rates. Koenig and Loucks (Koenig, Albert, and Loucks, 1977) provide a method for deriving an irrigation schedule based on climatological data for a given soil's drainage capacity, as well as the minimum combined area for land application and storage that meets certain nitrogen assimilative capacity. A design procedure based on hydraulic detention time which accounts for slope gradient, slope length, and surface roughness is described by Martel et al. (1980; 1982), with the intention of reducing site preparation costs. Smith and Schroeder (1983) developed and verified relationships between slope lengths and application rates. Their model predicts BOD and nitrogen removal and can be used as a rational method for system design. Some investigators recommend fairly extensive pretreatment facilities in their land treatment design; however, Thomas et al. (1976) states that pretreatment is needed only to remove solids.

Slope gradient and slope length are important variables in overland flow treatment (U.S. EPA, et al., 1974; Smith, 1982; Enviro Control, Inc., 1980; Smith and Schroeder, 1983; Martel, et al., 1982). Smith (1982), Hall et al. (1979), and Smith and Schroeder (1983) all found that wastewater treatment levels are independent of slope gradient between approximately 2-8% and that performance of overland flow is a function of slope length and application rate. Smith (1982) also found that BOD_5 removal varies inversely with application rate, while there were no differences for hydraulic loading between 2 and 6 cm/day.

An important design consideration is the monitoring of land treatment systems to prevent adjacent surface and ground water pollution, as well as to ensure that high quality effluent is being maintained. Pfannkuch and Labno (1976) lay out plans for ground water monitoring networks for pollution studies, including management considerations, design strategies, development of the monitoring network, and geologic considerations. Another monitoring system design for land disposal sites is presented by Walker (1974) as a guide for selecting the safest site for minimizing the danger to public health. Romero (1970) has developed recommendations for spacing wells adjacent to land treatment sites to prevent potential contamination. He points out that bacteria and viruses travel with the flow of water and do not travel or move against the current. He further states that, because of the many variables involved in the determination of a "safe" distance between a domestic well and a potential source of pollution, no single set of distances will be reasonable for all conditions. Salt content can be a problem in arid areas. Bower (1974) warns that recharge of sewage effluent may degrade the quality of ground water because of the salt content of renovated water. Overland flow systems, although placed on relatively impermeable soil, still recharge a significant amount of water below ground.

TREATMENT PROCESSES IN OVERLAND FLOW SYSTEMS

Wastewater treatment systems can be broadly categorized as to using mechanical, chemical, or biological methods of treatment. The overland flow system uses all three methods of treatment in a complex treatment process (Martel, et al., 1982). The system is required to treat municipal wastewater which is variable and often contains metals that can influence crop quality, soil productivity and ground water quality (Elliott, 1977).

The mechanical or physical treatment mechanism is filtration. Suspended solids are removed from that portion of the water infiltrating the soil (Loehr, et al., 1979). It is reasonable to expect 20% deep percolation losses if the infiltration rate is 0.1 cm/hr, the hydraulic loading is 20 cm/wk, and the time of application is 40 hr/wk. In fact, Thomas et al. (1970) reported deep percolation losses ranging from 16% to 28% for the overland flow system at Paris, Texas. Filtration also occurs by settling due to the slow velocities of water movement and entrapment by grass and vegetative litter (Martel, et al., 1982; Thomas, et al., 1974). Removal rates of total suspended solids (TSS) is generally greater than 90% (Overcash and Pal, 1979). Under certain conditions, algae can increase TSS (Smith and Schroeder, 1983).

Chemical processes are generally limited to adsorption and precipitation. The constituents most affected by these processes are metals and phosphorus (Loehr, et al., 1979). Loehr et al. (1979) state that many potentially toxic elements, such as zinc and nickel, are positively charged, and their retention in soil is related to the cation exchange capacity of the soil. The EPA (U.S. EPA, et al., 1974) further states that a significant amount of metals can cross cell membranes and can be temporarily sequestered in plants and microorganisms.

Phosphorus is also partially removed by the chemical process. However, Loehr et al. (1979) state, "efficient removal of phosphorus can only be achieved where intimate contact between the soil and wastewater is achieved, making overland flow systems less effective." Thomas et al. (1974) achieved approximately 50% phosphorus removal; while Overcash and Pal (1979), in summarizing data from overland flow systems treating municipal wastewater, found an average phosphorus removal of 50%.

The biological processes are well-documented, with removal rates exceeding 95% for overland flow systems treating municipal wastewater (Stevens, 1972; Overcash and Pal, 1979; Hall et al., 1979; Thomas, et al., 1976; Seabrook, 1979; Thomas, et al., 1974; Dept. of the Army, 1980; Smith and Schroeder, 1983; Martel, et al., 1982). Thomas et al. (1974) state that a well-operated system should produce an effluent with less than 10 mg/l of biochemical oxygen demand, while removing 70% to 90% of the total nitrogen. The majority of the nitrogen removal occurs due to biological processes. Iskandar (1981) reports that nitrogen is removed by adsorption of NH_4 by the soil surface, nitrification of NH_4, transport of NO_3 to the anaerobic zone, and removal by plant uptake and denitrification.

PHOSPHORUS AND NITROGEN REMOVAL

Alexander (1977) discusses microbial transformations in the phosphorus cycle, while Iskandar (1982) summarizes phosphorus removal by land treatment methods, including overland flow. The limiting factors in phosphorus treatment are listed by Loehr et al. (1979) and Reddy and Graetz (1981) and include pH, alkalinity, the concentration of soluble phosphorus in the water, interstitial phosphorus concentration in underlying sediment, and the adsorption-desorption characteristics of soils. Some phosphorus is removed by plants. Hill and Sawhney (1981) found that phosphorus movement is extremely slow in soil and that anaerobic conditions enhance phosphorus mobility. Over a long time period, the wastewater renovation phosphorus sorption capacity is reduced, but periodic rests regenerate system sites (Iskandar, 1981; Hill and Sawhney, 1981). Most of the phosphorus in soil is transferred into unavailable forms. Aluminum and organic matter in the soil are primarily responsible for phosphorus adsorption, with iron playing a secondary role (Vijayachandran and Harter, 1975). Logan and McLean (1973) found that phosphorus leached significantly through soil only when it was sandy, and only at a very high application rate. The EPA (U.S. EPA, et al., 1974) and Iskander (1981) also provide a general description of phosphorus removal processes.

Payne (1981) explains the nitrogen cycle and lists nitrifying and denitrifying organisms. The nitrogen removal process is described by Iskander

(1981), Loehr et al. (1979), Anonymous, (1974), EPA (U.S. EPA, et al., 1974), and EPA (Enviro Control, Inc., 1980). Lance (1972; 1974) provides a detailed analysis of nitrogen removal mechanisms in the soil. These mechanisms include: 1) denitrification, for which the three conditions most difficult to meet are the occurrence of nitrification, the passage of nitrate to the anaerobic zone, and the presence of an adequate energy source in the anaerobic zone for denitrification to occur; 2) volatilization of ammonia; 3) adsorption of the ammonium ion by negatively charged clay particles and organic colloids of the soil; 4) fixation of the ammonium ion by clays; 5) fixation of ammonia by organic fractions; 6) incorporation of nitrogen into cell tissues; 7) removal of nitrogen by vegetation; and 8) the loss of gaseous nitrogen by chemo-denitrification. Denitrification is the major source of nitrogen removal in overland flow systems (Thomas, et al., 1976). Some increase in the nitrogen content of the soil occurs over time (Lance, et al., 1976). Factors which affect nitrogen uptake by plants include plant composition, plant and root ages, supply of phetosynthate, nutrient form, root distribution, and soil moisture level (Iskandar, 1981). Nitrification, and consequently denitrification, are inhibited by extreme pH levels, excessive ammonia concentrations, temperature extremes, trace organics which are toxic (such as phenol), lack of a readily-available carbon source and a large population of microbes, a shortage of oxygen for nitrification and oxygen surplus for denitrification (Alexander, 1977; Iskandar, 1981; U.S. EPA, et al., 1974; Patrick and Reddy, 1976). The application rate and schedule also strongly determine the fate of nitrogen in soils because alternate flooding and drying periods are necessary for consistent nitrogen removal (Iskandar, 1981; Lance and Whisler, 1972). Small scale test models of overland flow show the existence of aerobic and anaerobic zones in the soil mass which facilitate nitrification and denitrification (Khalid, et al., 1981). If these alternate zones do not exist, then nitrogen treatment levels are lower. Ammonia is the easiest form of nitrogen to remove by overland flow, and organic nitrogen can also be effectively removed (an exception is that derived from algae). But, nitrate is difficult to remove since it has little affinity for soil material and remains in a mobile liquid phase (Duscha, 1980). Much nitrate will remain untreated, principally because there is insufficient carbon in wastewater for sufficient denitrification to occur. Soil consisting of silt and organic matter has been found to remove nitrogen better than sand does. Optimal conditions for nitrification and denitrification are discussed by Lance et al. (1976), Khalid et al. (1981), Ford et al. (1980), Chen and Patrick (1980). The most nitrogen is removed when these two processes can occur simultaneously. Smith and Schroeder (1983) and Martel et al. (1982) provide a mathematical relationship for the decrease in ammonia and TKN in the wastewater as it travels down the overland flow plots.

EFFECTIVENESS OF WASTEWATER TREATMENT IN OVERLAND FLOW

Treatment levels of effluent from overland flow are generally quite high during the entire year in warm climates, and during the summer season in cold climates. Some references compare the effectiveness of overland flow treatment to that of conventional tertiary treatment (Stevens, 1972; Thomas, et al., 1976; Seabrook, 1975), and another rates it the same as conventional secondary treatment (Abernathy, 1983). A review of published effluent qualities for overland flow systems shows quite variable results (Stevens, 1972; Overcash and Pal, 1979; Hall et al., 1979; Ketchum, et al., 1979; Grier and Burton, 1979; Thomas, et al., 1976; Seabrook, 1975; Thomas, et al., 1974; Witherow, 1981; Abernathy, 1983; Khalid, et al., 1981; Enviro Control, Inc., 1980; Smith and Schreoder, 1983; Martel, et al., 1982; Overcash, et al., 1976). Overcash and Pal (1979) present a summary of several overland flow treatment projects, the majority of which show warm-weather removal rates in excess of 90%. In the overland flow system described by Hall et al. (1979), phosphorus reduction was minimal, and fecal coliforms were not greatly diminished. This same study showed that in subfreezing temperatures chemical oxygen demand (COD), BOD, and ammonia treatments were hampered, but other treatment levels remained unchanged. Ketchum et al. (1979) describes the relationship in cold climates between effluent quality and treatment plot lengths, plus flow rate versus effluent quality. Thomas et al. (1976) found overland flow to be reliable, with a consistent effluent quality. Australia's long term overland flow system produced up to 100% treatment for all parameters except phosphorus, which had a 35% removal rate (Seabrook, 1975). In a laboratory overland flow simulation conducted by Chen and Patrick (1980), it was found that 80% of the nitrogen was removed. The removal rate was increased to 95% after a carbon source was added to the simulated wastewater.

A small-scale test model of overland flow shows where alternate aerobic and anaerobic conditions were maintained with controlled soil moisture, ammonia removal increased to 60%, and of the amount, 23-62% was due to plant uptake of nitrogen, and only 5% to ammonia volatilization. It was also found that phosphorus removal was greatly enhanced by the addition of lime (Khalid, et al., 1981). Overland flow treatment of BOD_5 is adequate at soil temperatures of 4°C and improves up to 14°C, while organics are removed by overland flow at all temperatures (Enviro Control, Inc., 1980). Also nitrogen is effectively removed, while phosphorus removal is quiet variable, and both of these are much reduced in wintertime. Furthermore, the EPA has shown that preapplication treatment of raw wastewater, since it creates a lower oxygen demand, reduced the efficiency of overland flow removal of nitrogen and phosphorus. Smith and Schroeder (1983) find that nitrogen removal is very time and temperature dependent, and that steady state performance is not achieved for some time after the initial startup of an overland flow system.

Several references discuss the effects of land treatment of wastewater on soil and plants within the system after certain periods of operation. Although these studies were not overland flow systems, they provide a valuable insight on how an overland system will most likely respond. After six years of applying of swine lagoon effluent to grass, there were no evident detrimental effects on soil or nutrient imbalances in the plants (Westerman, 1983). Application of sewage to mountain meadows resulted in higher plant concentrations of sodium and manganese, but found that the influence of the effluent on ground water quality and soil characteristics posed no serious health or environmental problems (Sabey, et al., 1981). After four years of land treatment of sludge, no unusually high concentrations of heavy metals were found in crop or soil samples, and soil organic matter increased by only 0.5% (Halderson and Peterson, 1976). On the other hand, Palazzo (1976) discovered greater concentrations of heavy metals in forages receiving the greatest rate of wastewater, and found that over time soil pH was reduced and soluble phosphorus in the soil increased. With systems such as the Werribee farm system at Melbourne, Australia, operating successfully for over 40 years

(Seabrook, 1975), it appears that long term effects of overland flow on the soil-plant system are non-detrimental.

HEALTH PROBLEMS ASSOCIATED WITH OVERLAND FLOW

A number of concerns arise in relation to possible health hazards involved with overland flow wastewater treatment systems. There have been no specific studies on health effects related to overland flows. Again, implications from other types of land treatment systems will apply to overland flow systems. Some of the commonly mentioned worries include: 1) contamination of human food crops grown on an overland flow site; 2) spread of disease by wildlife and insects coming in contact with sewage at the site; 3) contamination of nearby surface or ground water supplies; 4) airborne spread of disease from spray application; 5) accumulation of toxins, such as nitrate, in livestock forage grown at the site; 6) toxicity of sewage constituents to plants and soil microorganisms which could decrease treatment effectiveness; and 7) bacterial formation of carcinogenic nitrosamines (Alexander, 1977; Stevens, 1972; Iskandar, 1981; Loehr, et al., 1979; U.S. EPA, et al., 1974; Sorber and Guter, 1975; Overcash, 1976; Enviro Control, Inc., 1980). Alexander (1978) found there to be no evidence of nitrosamine formation from bacterial transformations of nitrogen. Several references state that disease bearing bacteria and viruses are very effectively removed by land treatment (Iskandar, 1981; Loehr, et al., 1979; Elliott, 1977; Gilbert, et al., 1976; Benarde, 1973; Gilbert, et al., 1976; Enviro Control, Inc., 1980). Pathogens will die on the soil surface away from the body and due to the effects of ultraviolet radiation, increased oxygen, nitrification and other environmental changes. Those that penetrate deeper into the soil will be protected from some of these effects, but a number of studies have shown that disease carrying bacteria will be totally removed within a few feet of soil (Romero, 1970; Drewry and Eliassen, 1968; Sorber and Guter, 1975; Gilbert, et al., 1976). Removal occurs by mechanical and biological straining and/or death due to environmental changes. Soil of a small particle size is best for this removal. When wastewater can drain down through ground fissures or fractured substrata, then pathogens can travel a great distance and survive for many days (Drewry and Eliassen, 1968; Allen and Morrison, 1973; Hanks, et al., 1981). Christensen (1982) presents a method for the concentration and removal of enteroviruses from water. A number of studies claim that no bacteria or viruses are found in the air around a land treatment site (Stevens, 1972; Hall, et al., 1979; Enviro Control, Inc., 1980). Overland flow has been found to present no hazards to livestock (Seabrook, 1975; Enviro Control, Inc., 1980).

Other studies have found that land treatment does cause some very real health hazards. Loehr et al. (1979) has discovered that pathogens will survive for extended periods on soil vegetation. Irrigation of alfalfa with sewage resulted in the death of fecal coliforms after exposure to ten hours of bright sunlight, but the fecal coliforms survived for much greater periods during cool, damp, overcast conditions (Bell, 1976). The same researcher found that it took fifty hours of exposure to bright sunlight to kill all fecal coliforms on reed canarygrass. This fatal-exposure time was because effluent collected on the under sides of grass sheaths where they were shaded (Bell and Bole, 1976). Larkin, et al. (1976) found that poliovirus persisted on vegetable crops for up to thirty-six days.

THE FAILURES OF OVERLAND FLOW IN COLD CLIMATES AND WAYS TO ALLEVIATE THESE PROBLEMS

The greatest drawback to the use of the overland flow method of wastewater treatment is that it operates poorly in the winter months in cold climates. This is typically because ice forms on the treatment site, and plant and microbial growth on the site is reduced. Ice formation prevents the proper flow of wastewater over the soil surface, and microbial populations are very sensitive to climate changes (Stevens, 1972). Hall et al. (1979) found that BOD_5, COD, and ammonia treatments were hampered in subfreezing temperatures. The EPA (U.S. EPA, et al., 1974) has determined that nitrification and denitrification will not occur when the soil temperature is below freezing. An overland flow treatment project for poultry processing water, operating in a cold climate, could not meet effluent guidelines in freezing periods (Ketchum, et al., 1979). That study includes a discussion of the effect of temperature on the treatment of each waste constituent. The percentage of nitrogen in the soil increases with the decrease of mean annual temperature. Low temperatures have a much greater effect on anaerobic processes than on aerobic processes. In a study by Smith (1982), low microbial survival and altered dissolved oxygen concentrations during ice cover were found to be problems in winter.

A number of solutions have been proposed to help alleviate these problems. Several of the authors suggest storing wastewater in the winter in lagoons or as ice on the treatment plots during the winter (Stevens, 1972; Smith and Schroeder, 1983). Icing over the plots often prevents the soil below from freezing so that nitrification can still occur in the soil. Stevens (1972) also suggests raising the temperature of the water applied to land in winter. Several researchers (Ketchum et al., 1979; Sabey, et al., 1981; Enviro Control, Inc., 1980) recommended reducing the winter loading rate. It is believed that this will increase treatment levels. Ketchum et al. (1979) also suggest returning unsatisfactory winter effluent for further treatment, and they believe winter waste application must continue to maintain a microbial population capable of treating the wastewater just after spring thaw. Borrelli et al. (1978) discuss management problems for severe cold conditions and provide a management and design scheme for a sprayfield in winter. Alter's (1969) survey of sewage disposal in Alaska shows that biological processes offer the most promise for use under low temperatures since certain psychrophilic organisms can operate effectively in waste stabilization processes. The Department of the Army made recommendations on how to maintain a high nitrogen removal rate by winter crop management (1980). Smith (1982) details existing wastewater management techniques for cold regions. It is apparent that more research is needed in this area before overland flow will become a truly feasible mechanism for year round treatment of wastewater in cold regions.

APPENDIX E

REFERENCE SAMPLES FOR WATER QUALITY ANALYSES

TABLE 41. AMMONIA-N REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
N 7	5/28/82	1.90	1.735	0.234	0.17
DMRQA002	6/25/82	2.4	2.51	0.12	-0.92
N 8	11/24/83	0.23	0.185	0.084	0.54
DMRQA003	5/11/83	8.56	8.56	0.31	0.00
N 9	5/26/83	0.47	0.356	0.206	0.51
N 10	11/28/83	1.08	1.191	0.249	-0.45
N 11	"	0.22	0.160	0.012	5.00

TABLE 42. NITRITE-N REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
N 7	5/28/82	0.49	0.472	0.079	0.23
N 8	11/24/83	0.11	0.050	-	-
N 9	5/26/83	0.23	0.20	0.061	0.49
N 10	11/28/83	0.01	0.008	0.005	0.40
N 11	"	0.02	0.014	0.005	1.20

TABLE 43. NITRATE-N REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
N 7	5/28/82	3.1	2.91	0.36	0.52
DMRQA002	6/25/82	0.30	0.352	0.019	-2.74
N 8	11/24/83	0.36	0.41	0.08	-0.62
DMRQA003	5/11/83	2.64	2.74	0.093	-1.07
N 9	5/26/83	4.3	4.28	0.56	0.04
N 10	11/28/83	2.43	2.478	0.141	-0.34
N 11	"	4.03	3.962	0.279	0.24
M 80	5/28/83	0.50	0.546	0.071	-0.65
WS 011 1	11/19/82	0.18	0.15	0.0122	1.33
WS 011 2	"	8.88	9.10	0.325	-0.67
M 82	11/24/82	0.10	0.02	0.04	----
WS 012 1	5/23/83	2.08	2.12	0.08	-0.50
WS 012 2	"	1.14	1.13	0.05	0.20
M 84	5/26/83	4.0	3.94	0.45	0.13
M 86	11/28/83	3.49	3.975	0.392	-1.24
WS 013 1	11/18/83				
WS 013 2					

TABLE 44. SPECIFIC CONDUCTANCE REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
M 80	5/28/82	498	485.7	29.5	0.42
M 82	11/24/83	148	138.9	9.0	1.01
M 84	5/26/83	1150	1098	69	0.75
M 86	11/28/83	887	859	47.8	0.59

TABLE 45. pH REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
M 80	5/28/82	8.1	8.08	0.19	0.15
DMRQA002	6/25/82	6.47	6.45	0.048	0.41
WS 011	11/19/82	7.0	7.1	0.15	-0.66
M 82	11/24/83	7.3	6.89	0.42	0.98
DMRQA003	5/11/83	5.20	5.10	0.038	2.61
WS 012	5/23/83	8.7	9.1	0.15	-2.62
M 84	5/26/83	8.1	8.09	0.17	0.06
M 86	11/28/83	7.8	8.13	0.20	-1.65
WS 013	11/18/83				

TABLE 46. P-TOTAL REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
N 7	5/28/82	1.4	1.57	0.19	-0.89
DMRQA002	6/25/82	0.90	0.91	0.037	-0.30
N 8	11/24/83	0.00	0.039	0.033	-1.18
DMRQA003	5/11/83	3.40	3.37	0.085	0.35
N 9	5/26/83	1.4	1.68	0.23	-1.22
N 10	11/28/83	1.2	1.432	0.152	-1.53
N 11	"	0.50	0.515	0.061	-0.24
M 80	5/28/82	0.74	0.727	0.087	0.15
M 82	11/24/82	0.06	0.162	0.038	-2.68
M 84	5/26/83	0.60	0.65	0.08	-0.62
M 86	11/28/83	0.42	0.497	0.066	-1.17

TABLE 47. TKN REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	13.5	13.3	0.73	0.27
DMRQA003	5/11/83	1.8	1.15	0.11	5.82

TABLE 48. PO4-P REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
N 7	5/28/82	0.27	0.291	0.064	-0.33
DMRQA002	6/25/82	3.61	3.69	0.108	-0.74
N 8	11/24/83	0.00	0.017	0.017	-1.00
DMRQA003	5/11/83	1.01	0.973	0.022	1.65
N 9	5/26/83	1.0	1.08	0.08	-1.00
N 10	11/28/83	1.1	1.001	0.077	1.29
N 11	"	0.50	0.487	0.044	0.30

TABLE 49. BOD5 REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	72.4	61.1	7.93	1.42
DMRQA003	5/11/83	123	109	13.97	1.00

TABLE 50. COD REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	91.9	92	5.73	-0.02
DMRQA003	5/11/83	154	165	8.17	-1.34

TABLE 51. TOC REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	32	36.1	3.02	-1.36

TABLE 52. OIL AND GREASE REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	8.3	6.0	0.973	2.56
DMRQA003	5/11/83	12.5	10.0	1.63	1.54

TABLE 53. TOTAL SUSPENDED SOILDS (TSS) REFERENCE SAMPLES

Sample	Date Reported	Value Reported	Mean	Standard Deviation	No. of Deviations
DMRQA002	6/25/82	42.4	44.2	2.633	-0.36
DMRQA003	5/11/83	28.2	29.0	1.667	-0.48